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SEDS

SYSTEM EFFECTIVENESS DATA SYSTEM

TRW SYSTEMS GROUP

Redondo Beach, California

March 1968

Dr. N.S. D'Andrea Du Bois, Jr.
Dr. B. Ostrofsky
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Prepared for

Space and Missile Systems Organization
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FOREWORD

The System Effectiveness Data System (SEDS) Study was performed by TRW Systems, Redondo Beach, California, under contract number F04 697-67-C-0002. The program continued from 1 October 1967 to 15 March 1968 and was monitored by Mr. E. A. Denning (SAMSO/SMSIR). This document was submitted for final approval 1 March 1968.

The TRW Systems personnel contributing to the SEDS program and this report were Drs. N. S. D'Andrea DuBois, Jr.; B. Ostrofsky; Messrs. T. S. Arnold; J. Cook; J. A. Jones (SMSgt, USAF, Ret); J. McGivern; W. A. Ulman and other support personnel. The following Air Force personnel and activities also contributed directly to the SEDS program: Mr. E. A. Denning (SAMSO/SMSIR); Lt. Col. R. R. Stanton (AFSC/SCS-22); Major T. D. Hill, Edwards AFB Flight Test Center (FTTED); and personnel of the Data Automation Division (FTTSD) Edwards AFB, California.

This technical report has been reviewed and is approved.

R. G. Oakes

R. G. OAKES
Deputy Chief, Tech
Requirements and Stds Ofc

ABSTRACT

This report represents the continued development effort of SEDS for the time period 1 November 1967 to 15 March 1968. The effort was conducted at Edwards AFB on the IBM 7044/7094 computer. F-111A Category II operating data (AFSC 258/258-4 and the Mission Debriefing Form) was stored on tapes using the IBM Formatted File System (FFS-V8). Problems were defined by the F-111 System Project Office (SPO) and the Air Force Logistics Command Sacramento Material Area (AFLC/SMAMA) for which solutions were to be obtained. These problems were associated with the eleven most Critical Line Replaceable Units (LRU) in the F-111 which were defined for SEDS by SMAMA and the resident provisioning team (RPT) at Fort Worth. The problems were:

(1) Distribution of total maintenance for each LRU.

(2) Relationships between LRU replacement and failure (maintenance descrepancy).

(3) Replacement estimate for each mission type.

(4) Estimate for replacements per 100 flying hours for each LRU.

Solutions were provided within the allotted time period for these problems while simultaneously proceeding with the programming activities to make (FFS-V8) operational.

Solutions were provided for problem (1) for both flight line and shop activities where the event was defined as all activities associated with the total system. Problems (2) and (3) were solved as planned. Problem (4) was solved as planned with the additional result of the probability distribution associated with each LRU replacement requirement. That is, the probability of not exceeding a given replacement value was provided.

This study demonstrated that storage and retrieval of a large volume of operating and maintenance data on a timely basis appears feasible. Also that Category II operating data can be used to provide relatively accurate estimates of system operating parameters and/or requirements. This study further demonstrates the usefulness of the 258/mission debriefing data for providing estimates of reliability/maintainability parameters and other information.

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LIST OF ABBREVIATIONS

A/C	Aircraft
ACTAK	A code which describes a maintenance action taken.
AF	Air Force
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AFLC	Air Force Logistics Command
AFSC	Air Force Systems Command or Air Force Speciality Code
BSD	Ballistic Systems Division
COBOL	COmmon Business Oriented Language, a computer language by which business data processing may be precisely described in a standard form.
DCS	Direct Couple System, a computer with an IBM 7044 for input/output and an IBM 7094 as the main computer.
EAFB	Edwards Air Force Base
FORTRAN	FORmula TRANslator, a compiler language developed by the IBM Corporation originally conceived for use on scientific problems but now widely adapted for most commercial problems as well.
FFS	Formatted File System, a computer system program used by the Strategic Air Command as an integral part of the Intelligence Data Handling System.
HOW MAL	A code which describes how a system component malfunctioned.
IBJOB	An IBM computer program that operates under the control of IBSYS and monitors and controls the compilation, assembly and execution of computer jobs processed on the IBM 7094 computer.

LIST OF ABBREVIATIONS (Continued)

IBSYS	An IBM computer program which monitors and controls the operation and job through put on the IBM 7094 computer.
LRU	Line Replaceable Unit
MAP	Macro Assembly Program, a symbolic programming language developed by the IBM Corporation which permits detail operation on information in the IBM 7094.
P/N	Part Number
PPRN	Report Number
ORN	Original Report Number
RIMS	Reliability Information Monitoring System
S/N	Serial Number
SAC	Strategic Air Command
SAMSO	Space and Missile Systems Organization
SECAP	System Experience Correlation and Analysis Program
SEDS	System Effectiveness Data System
SMAMA	Sacramento Air Materiel Area of the Air Force Logistics Command
SPO	Systems Project Office
WUC	Work Unit Code
4K	4000 series code which describes aircraft functions as denoted on the Mission Debriefing Form.

1.0 INTRODUCTION

In order to study the problem of automatically storing and retrieving the type of information needed to estimate effectiveness parameters of weapon systems the Air Force Systems Command (AFSC) at Norton Air Force Base, California, initiated the Reliability Information and Monitoring System (RIMS). For details see the Ballistic Systems Division, Report No. BSD-TR-64-169. This initial effort has been extended under Reliability Information/Monitoring System Capability Demonstration Project, Report No. BSD-TOR-669 (S6855-12)-1, System Experience Correlation and Analysis Program (SECAP), Space and Missile Systems Organization (SAMSO) Report No. 67-12 and the System Effectiveness Data Systems (SEDS) which is covered in this report. SEDS is an exploratory development effort to enhance Air Force data storage, retrieval, and analysis capability of weapon systems' mission performance data. In this current study the following areas are investigated: (1) the distribution of maintenance events, (2) the relationship between replacements and failure indications, (3) the expected number of replacements per mission type, and (4) the estimated replacements per 100 flying hours for each LRU. The above areas are studied in connection with F-111 Category II Testing Program at Edwards AFB, California. However, the techniques developed here can be applied to other weapon systems.

1.1 HISTORY OF THE PROJECT

The System Effectiveness Data System (SEDS) study is an extension of the work accomplished under the System Experience Correlation and Analysis Program (SECAP) (SAMSO Report No. 67-12).

SECAP was an exploratory development effort to enhance AFSC data storage, retrieval, and analysis capability, particularly in the areas of reliability, maintainability, and effectiveness evaluation. This effort was accomplished at Norton Air Force Base, California, using AFSC/258 and the Mission Debriefing Form (0-294).

The SECAP effort was preceded by the Reliability Information Monitoring System (RIMS) study, BSD Reports No. TR-64-169 and No. TOR-669 (S6855-12)-1. This study considered the feasibility of using a computer

implemented storage and retrieval system for storing and retrieving reliability and maintainability histories on weapon systems. As a result of this study the IBM Formatted File System (FSS) developed for the Air Force Strategic Air Command (SAC), under contracts AF 19(628)-525 and F 30(602)-67-C-0252, was implemented on the IBM 7094 Computer at Norton Air Force Base, California, using reliability and maintainability data for Minuteman and early Category II Tests Data for the F-111 as a data base. In order to analyze the information retrieved from the above data base, a statistical analysis capability was developed under SECAP.

In order to develop an on site capability the project was moved to Edwards Air Force Base, California, and given tasks to perform for the SPO while simultaneously developing a subsequent form of the automated file for storage and retrieval of Category II operations data at EAFB. The tasks were primarily to determine if products could be developed to support AFLC provisioning activities at McClellan AFB, Scaramento, California (SMAMA). Since the Formatted File System was being updated for current manipulation by EAFB personnel, products from the study were largely experimental in nature and provided a real measure of potential for the F-111 data and SEDS by illustrating timely and successful achievement of the desired products for AFLC provisioning.

1.2 REQUIREMENTS FOR SEDS

Engineers concerned with reliability, maintainability and provisioning planning for weapon systems usually have to make assumptions concerning the performance of the system under consideration. Obviously, provisioning requirements based on the assumed performance of a weapon system will be inadequate. Thus, in order to provide accurate estimates of the provisioning requirements associated with a maintenance policy for any weapon system, it is necessary that actual performance data be available. In this regard, the purpose of SEDS was to develop a program for providing estimates of parameters and/or criteria for measurement of operational effectiveness from actual data. This was approached by

(1) Implementing an operational/maintenance data base using an IBM 7094 computer facility at Edwards AFB.

(2) Developing analytical techniques and models which could be used with the data base for producing parameters and/or distributions of parameters for evaluating F-111A Category II operational performance.

(3) Providing a method for extending this measurement capability to the using Commands to improve management decision-making.

1.3 DUALITY OF CURRENT EFFORT

To accomplish SEDS the AFSC 258 and mission debriefing data were stored in the Edwards AFB computer and used during subsequent activities to produce products. Because of current USAF budgeting problems it was decided to accelerate the time frame for the total activity and simultaneously attempt to alleviate some current problems for the F-111 SPO. At their direction, the provisioning team at SMAMA and at Fort Worth were included in the coordination effort and agreement reached on several urgent problems for which the SEDS activities appeared to be helpful.

Consequently, the SEDS program was placed in the position of providing solutions to existing problems prior to having FFS operational at EAFB. It is to the credit of EAFB and contractor personnel that useful solutions were provided within the allowed time period while development of the basic data system continued. It is of interest to note that the products for F-111 SPO (Section 5. 1 through 5. 5) could have been produced in approximately one-third of the time had the 258/debriefing data been completely debugged when the current study began.

2.0 RESOURCE AVAILABILITY

The basic resources required by SEDS are as follows:

(1) A computer system with the IBM Formatted File System, FORTRAN IV and COBOL installed.

(2) Technical personnel as described in the SECAP Report (SAMSO 67-12).

(3) A data base containing maintenance and mission debriefing data on the weapon system of interest.

A complete description of the resources available to SEDS is discussed in the following sections.

2.1 COMPUTER FACILITIES

The computing facilities at Edwards AFB (FTTSD) were made available to the SEDS working group. The computer hardware consisted of a Direct Coupled System (DCS), i.e., an IBM 7044/7094 Model I with a card read/punch, six magnetic tape units, a double module 1301 disk and two printers. The basis operating system for the IBM 7044 at FTTSD is code named "IRETMUPOS" (INTEGRATED REAL-TIME MULTIPROCESSOR OPERATING SYSTEM). In general IRETMUPOS controls the job throughput for DCS. On the other hand, the basis operating system for the IBM 7094 is IBSYS (Version 13) which contains SORT, IBJOB, UPDATE and FFS as subsystems.

2.2 PERSONNEL UTILIZATION

Under SECAP requirements for technical personnel necessary for the analysis and development of automated solutions of systems effectiveness data reduction problems were developed. The composition of the SEDS team was based on these requirements (SAMSO Report No. 67-12).

Four to eight individuals possessing the above qualifications were assigned to SEDS and utilized as required to solve the problems posed in Section 5.0 through 5.5. Two of these individuals were management and analytically oriented and the remaining personnel were computer and Air Force maintenance oriented.

2.3 SYSTEMS DATA HISTORY AND AVAILABILITY

Two sources of data have been used as a base for problem solving associated with SEDS. Both data bases are related to Category II, F-111A aircraft undergoing tests at Edwards Air Force Base, California.

The first source used was hardware oriented, collected by maintenance personnel on the "Maintenance Discrepancy Production Credit Record," AFSC Form 258 (hereafter referred to as 258 data, see Figures 2.3.1 and 2.3.2). This form is used for recording "on equipment" maintenance actions and includes "Support general" work, removal and reinstallation of components, fix-in-place repair actions, installation of an item when accomplished separately from the removal action, recording functional checks, partial job completions, trouble shooting actions, etc. "Support general" and "on equipment" maintenance actions are not to be documented on the same form.

Each report in the 258 system is considered to be a line item record. There were 11,533 records in this data base, dating from January 1966 through September 1967.

The second source of data was functionally oriented. These data are collected from the pilots, at debriefing after each flight (see Figures 2.3.3 and 2.3.4). An AFFTC Form 0-294 is used to record satisfactory, degraded or malfunctioned condition of each functional subsystem, and for each phase of the flight. Each functional item listed has a 4000 series number to identify it for coding purposes. The form also provides for pilot's comments.

Each report in the debriefing data base covers approximately 200 functional bits of information. There were 37,258 records in this data base, resulting from approximately 200 flights from January 1966 through September 1967.

A discussion of the necessary and desirable properties of a data system required for weapon systems effectiveness studies is given in Section 4.0.

	A. JOB CONTROL NUMBER	B. PRI	C. TIME SPEC REQD	D. WORK AREA	E. ESTIMATED MANHOURS	F	1. COPY NR 0	2. REPORT NUMBER № 315000
10	3. BASIC WORK CENTER	4. ITEM IDENTIFICATION		5. SERIAL NUMBER	6. TIME CYCLES MILES	7. WHEN DISCOVERED TIME (Day-Mo-Yr-Hours)
	8. DATE THIS REPORT (Day-Mo-Yr)	9. WORK ORDER NUMBER		10. ORIG REPORT NUMBER	11. WHEN DISC CODE	12. ENG POSN NO	13. ACTIVITY IDENT
	FAILED ITEM					
20	14. MANUFACTURER	15. NOUN - ENGINE TYPE MODEL SERIES MOD		16. SERIAL NUMBER	17. TIME CYCLES/MILES	18. PART NUMBER
	19. WORK UNIT CODE	20. SYMBOL	21. HOW MAL	22. FEDERAL SUPPLY CLASS	23.	24.
	INSTALLED ITEM					
30	25. MANUFACTURER	26. NOUN - ENGINE TYPE MODEL SERIES MOD		27. SERIAL NUMBER	28. TIME CYCLES/MILES	29. PART NUMBER
40 THRU 49	G. SUPPLY DOCUMENT NUMBER *(Issue or Demand)*			30. DESCRIPTION OF DISCREPANCY OR MAINTENANCE REQUIRED		
						H. DISCOVERED BY

	31. PRE FIX	AFSC	SUF	NR	32. START	33. STOP	34. DELAY CODE	35. START	36. STOP	37. DELAY CODE	38. WORK UNIT CODE	39. ASSISTING WORK CENTER	40.	41.
50														
51														
52														
53														
54														
55														
56														
57														
58														
59														

60	42. T.O. NUMBER	43. T.O. DATE (Day-Mo-Yr)	44. T.O. PROCEDURE	45. TOOLS/AGE	I. CORRECTED BY
61 THRU 69	46. CORRECTIVE ACTION				J. INSPECTED BY
	K. SUPERVISOR	L. RECORDS ACTIONS ☐ UNCLEAR DISCREPANCY ☐ REPLACEMENT TIME CHANGE ☐ DATA TRANSCRIBED TO RECORDS	M. DATE TRANSCRIBED (Day-Mo-Yr)	N. TRANSCRIBED BY	

Figure 2.3.1. Sample AFSC 258 Maintenance Discrepancy/ Production Credit Record

47. PIECE PARTS REPLACED DURING REPAIR

70 THRU 79

PART NUMBER	NOUN	WORK UNIT CODE	CIRCUIT SYMBOL	TYPE FAILURE PRI	TYPE FAILURE SEC	QTY	HOW MAL	MANUFACTURER	FSC

CODING TO BE IN BLOCKS AS INDICATED

BLOCK 34 AND 37 DELAY CODES

S AWAITING SUPPLIES AND/OR PARTS
C DELAY DUE TO CONFLICTING MAINTENANCE
A WORK STOPPAGE — NON-POWERED AGE OR RPIE
E WORK STOPPAGE — POWERED AGE OR RPIE
F FLYING
P AWAITING PERSONNEL ASSISTANCE
R ENGINE RUN-UP
T AWAITING TRANSPORTATION
X DELAY FOR WEATHER
K DELAY FOR SPECIAL TEST EQUIPMENT
M PREPLANNED MAINTENANCE DELAY

BLOCK 41 ACTION CODES

1. SERVICING
2. UNSCHEDULED MAINTENANCE
3. PREFLIGHT INSPECTION
4. POSTFLIGHT INSPECTION
5. HOURLY POSTFLIGHT
5. PERIODIC INSPECTION
7. SPECIAL INSPECTION
8. INDEPENDENT
9. RESEARCH AND DEVELOPMENT

BLOCK 44 T.O. PROCEDURE CODES

1. ADEQUATE
2. INADEQUATE
3. INCOMPLETE
4. MISIDENTIFIED
5. NOT AVAILABLE
6. INCORRECT INFORMATION
7. OTHER

BLOCK 45 TOOLS/AGE CODES

1. TOOLS ADEQUATE
2. TOOLS INADEQUATE
3. TOOLS NOT AVAILABLE
4. TEST EQUIPMENT ADEQUATE
5. TEST EQUIPMENT INADEQUATE
6. TEST EQUIPMENT NOT AVAILABLE
7. TOOLS AND TEST EQUIPMENT ADEQUATE
8. TOOLS AND TEST EQUIPMENT INADEQUATE
9. TOOLS AND TEST EQUIPMENT NOT AVAILABLE

Figure 2.3.2. Continuation of Sample AFSC 258 Maintenance Discrepancy/Production Credit Record

F-111 MISSION DEBRIEFING

CARD NR.	MISSION IDENTIFICATION DATA								
1	1. MISSION NR	2. ACFT NR	3. DATE DAY MO YR	4. TYPE MSN	5. SCHED TO HR MIN	6. ACTUAL TAKEOFF HR MIN			
	7. SCHED DURATION HR MIN	8. ACTUAL DURATION HR MIN	9. HIGH MACH	10. HIGH ALT	11. SUPER-SONIC TIME HR MIN	12. LH AB TIME HR MIN	13. RH AB TIME HR MIN	14. NUMBER LANDINGS	15. WING SWEEPS
	16. AIRCRAFT COMMANDER		17. PILOT ENGINEER						

		FLIGHT PROFILE										
	60											
	50											
	40											
ALT FT MSL (X 10^3)	30											
	20											
	10											
	0											

	PHASE CODE	B	C	D	E	F	G	H	I	J	K	L
	PHASE OF FLIGHT	START & PRE-TAXI	TAXI	TO AND ACCEL	CLIMB	CRUISE		COMBAT & WPN. DEL	RETURN		TRAFFIC PAT & LANDING	TAXI & SHUT DOWN
2	TIME OF DAY	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.
3	AVERAGE MACH				29.	30.	31.	32.	33.	34.		
	AVERAGE ALTITUDE					35.	36.	37.	38.	39.		

MISSION OBJECTIVE	PERCENT SUCCESS

REMARKS

Figure 2.3.3. Sample AFFTC 0-294 F-111 Mission Debriefing Form

CARD NUMBER	SYSTEM	PHASE OF FLIGHT												DISCREPANCY
		A	B	C	D	E	F	G	H	I	J	K	L	
		PRE-START	START & PRE-TAXI	TAXI	TO AND ACCEL	[illegible]	CRUISE		COMBAT & WPN DEL	RETURN		TRAFFIC PAT LAND	TAXI AND SHUTDOWN	
4001	AIRFRAME													
	LANDING GEAR													
4002	Anti-skid													
4003	Brakes													
4004	Nose Gear Steering													
4005	Arresting Hook													
	Extension Retraction													
4006	Normal													
4007	Emergency Extension													
4008	Tires													
4009	Tail Bumper													
4010	Other													
	PROPULSION													
	Engines													
4011	Left Basic Engine													
4012	Right Basic Engine													
4013	Left Afterburner													
4014	Right Afterburner													
4015	Other													
	Inlet System													
4016	Spike													
4017	Translating Cowl													
4018	FOD System													
4019	Other													
	Starting													
4020	Cartridge													
4021	Pneumatic													
4022	Air-Start													
4023	Cross-Bleed													
4024	Other													
	Oil System													
4025	Pressure													
4026	Quantity													
4027	Other													
	Fuel System													
4028	Fuel Transfer													
4029	Fuel Pressure													
4030	Fuel Dump													
4031	Air-Refueling													
4032	Fuel Flow													
4033	Other													
4034	Fire Detection & Extinguishing													
	Engine Instruments													
4035	Turbine Inlet Temperature													
4036	Tachometer													
4037	EPR													
4038	Nozzle Position													

Figure 2.3.4. Continuation of Sample AFFTC 0-249 F-111 Mission Debriefing Form

3.0 FORMATTED FILE SYSTEM

The Formatted File System (FFS) was developed for the Strategic Air Command as an Intelligence Data Handling System (see SAC contracts AF 19(628)-525 and F 30(602)-67-C-0252). It provides a method of efficient storage, maintenance and retrieval of large volumes of data utilizing the speed of large scale computers. FFS has been upgraded over the past several years to the current version or model. All references to FFS in this document are to version eight (FFS-V8). In general, FFS is a collection of interrelated IBM 7094 computer routines capable of operating on many different files of information. Any data which can be described as to size and location in the input media can be accommodated. This description of the data becomes a part of the data base and serves as the control for file processing.

To generate a file, the user describes the file to the system in the form of punched cards. This description includes the format of the line items (records) in the file, the various input formats that will be submitted to the file (10 maximum) and any standard output formats which will be required from the file (10 maximum). This description may be modified at any time; such as adding or deleting fields, and the data base will be automatically restructured.

In order to update a file the input information is submitted in the form of punched cards or magnetic tape with a control card indicating which of the ten available input formats is present. When updating, a file look up operation may be accomplished automatically. This procedure introduces data into line items according to matching codes in the input. Similarly, modification of the data base may be accomplished by submitting revised input formats or retrieving the desired line items and specifying changes or deletions.

Retrieval in FFS is accomplished by specifying, in formatted English statements, a set of criteria associated with any field, portion of a field, or group of fields in the data base. Processing of retrieved data includes sorting, arithematic operations, totals, subtotals, averages, etc. Output report generation ranges from simple statements requesting standard reports, to those which specify the exact positioning of data

vertically and horizontally in the output report. Graphic output, in the form of point and bar graphs, are also available.

3.1 INITIAL STATUS OF FSS

When the SEDS working group arrived on site at Edwards AFB, California, the IBM Formatted File System (FFS) had been installed as a subsystem under IBSYS on an IBM 7044/7094 Direct Coupled System (DCS). Modified FFS documentation and information describing the DCS operating system were made available.

Coordination with the DCS related AFFTC personnel revealed the following facts:

(1) FFS required modification mainly in the areas of input/output unit assignments and double-precision to single-precision conversion.

(2) The FFS capabilities of File Collation and Multi-file Query were not available, since the disk file was not attached to the IBM 7094.

(3) The System Report Program of FFS was not as yet modified for operation on DCS.

(4) The FFS System Graphic Output Program was not installed.

After reviewing the available documentation, the SEDS working group began operations with the data tapes transferred from Norton Air Force Base, California.

3.2 PROBLEMS ENCOUNTERED

As might be expected with the installation of a system the size of FFS, several problems were encountered. The following is a brief summary of problems experienced by the SEDS working group.

(1) Any task which required more than one history tape to be entered in the availability table of FFS failed. This failure was due to an error in the FFS System Input Program. Hence, several FFS functions requiring more than one history could not be performed.

(2) Attempts to produce an "ADD tape" by means of the file modification process (Type 12) and the file summarization process (Type 5) both failed. When corrected the "ADD tape" produced could not be used in a file add (FADD) process.

(3) File updating could not be accomplished due to the generation of an illegal tape address in FFS. After this error was corrected, it was found that an update operation failed if an error save tape was produced since the tape "ran away" in the update process. In addition, updating from tape, as opposed to cards, was not possible because the input tape was not correctly entered in the FFS System Availability Table.

(4) In using the Quick Query Function, the system failed to produce a diagnostic indicating an imbedded blank column in a write statement. The output produced was unusable.

(5) A Type 4 file summarization process could not be accomplished because a portion of the File Query Processor Program was being overlayed during its operation.

(6) File updating employing a stored FMUP package (SMUP function) fails and provides a diagnostic indicating that additional tapes are required. This conditions also occurs on a Type 3 file summarization process.

(7) An illegal tape address diagnostic has caused certain file update calculations to fail.

3.3 CURRENT STATUS OF THE SYSTEM

Many of the problems discussed in the previous section have been corrected by modifying FFS while other corrections are currently implemented through the use of octal patches submitted with the appropriate jobs. There remain, however, problems which require further definition and analysis to define the program in error and specific correction required. The following is a list of known errors which remain outstanding:

(1) The file add (FADD) function.

(2) The file updating function when an error save tape is generated.

(3) The diagnostic indicating additional tape requirements in SMUP and on Type 3 file summarization functions.

(4) The diagnostic "Illegal Tape Address" on certain FMUP procedures with calculation.

Additional comments can be found in Appendix I.

4.0 AIR FORCE MAINTENANCE PHILOSOPHY AND DATA SYSTEM

It was suggested in Section 1.0 that, if the effectiveness of a weapon system is to be considered, it is reasonably clear that reliability and maintainability histories of the components of the system should be available. Unfortunately, it is not obvious what questions should be answered or what problems should be solved when weapon system effectiveness is considered. If such questions and problems could be formulated precisely, there still remains the more difficult question concerning what information is needed to produce reasonable answers to weapon systems effectiveness questions. The Air Force approach to the data collection problem is summarized in Sections 4.1 through 4.5 below.

4.1 INFORMATION REQUIRED FOR SEDS

The information required to answer maintainability questions of the type given in Section 5.0 are related to the following considerations.

(1) A method of linking a series of related tasks stemming from an original maintenance requirement is mandatory (original Report Number, and tracking part number/ serial number of equipment).

(2) A method of identifying the hardware under study is also mandatory (name, part number/serial number, Work Unit Code).

(3) Why did the hardware require maintenance? (How Malfunctioned Code)

(4) When did the maintenance requirement become known? (When discovered, date and time)

(5) When was the maintenance requirement discovered: during other maintenance, during inspection, etc.? (When Discovered Code)

(6) How long did it take? (Start/stop time)

(7) What was done to restore the hardware to its operating state? (Action Taken Code)

The above terms are defined in the description of the management data blocks of the 258 data system.

4.2 AIR FORCE CONCEPT OF MAINTENANCE

In order to understand the type of data elements needed for maintainability studies, it is necessary to review the Air Force concept of maintenance. Generally, there are three major levels of maintenance in the Air Force which are known as Organizational, Field, and Depot with Organizational Maintenance divided into line and shop maintenance respectively.

Organizational line maintenance activity is conducted by a group of personnel who are charged with preflight, postflight, and daily inspections of a weapon system. The personnel are usually specialists who troubleshoot and repair malfunctions by using a block replacement policy or other easily removed and replaced items on the equipment which have been defined as "Line Replaceable Units," (LRU). The line organization also services equipment by refueling, lubricating, making minor adjustments and calibrations of equipment at the weapons system location (such as the flight line). On the other hand, organizational shop activities are conducted by a group of personnel who can bench check most of the LRU's removed at line level. Shop personnel may remove and replace subassemblies, circuit boards, easily removed hardware, lubricate where necessary, clean equipment, and adjust and calibrate to shop standard test equipment. More detail maintenance tasks are referred to Field Maintenance personnel who are authorized to perform major maintenance, such as engine overhaul, removal and replacement of electronic equipment to the component level. As might be expected field maintenance activities are limited by quantity and quality of test equipment and other shop facilities. Finally, equipment that cannot be repaired at field level maintenance is shipped to a depot (the "depot" may include the manufacturer). The Field Maintenance Organization makes appropriate entries to maintenance forms and shipping documents with a "Not Repairable This Station" (NRTS) Action Taken code from the Work Unit Code Manual (see Table 4.2.1). The depot may then completely overhaul and rebuild equipment as necessary.

Table 4.2.1. Action Taken Codes used for Maintenance Activities for the F-111

Code	Description	Code	Description
A	BENCH CHECKED AND REPAIRED	H	EQUIPMENT CHECKED - NO REPAIR REQUIRED (FOR "ON-EQUIPMENT" WORK ONLY)
B	BENCH CHECKED - SERVICEABLE (NO REPAIR REQUIRED)	J	CALIBRATED - NO ADJUSTMENT REQUIRED
C	BENCH CHECKED - REPAIR DEFERRED	K	CALIBRATED - ADJUSTMENT REQUIRED
D	BENCH CHECKED - TRANSFERRED TO ANOTHER BASE	L	ADJUST OR RESET - INCLUDES TIGHTEN, ADJUST, BLEED, BALANCE, RIG, FIT, OR ACTUATING RESET BUTTON OR SWITCH
1	BENCH CHECKED - NRTS (NOT REPARABLE THIS STATION) REPAIR NOT AUTHORIZED	M	DISASSEMBLE
2	BENCH CHECKED - NRTS - LACK OF EQUIPMENT, TOOLS, OR FACILITIES	N	ASSEMBLE
3	BENCH CHECKED - NRTS - LACK OF TECHNICAL SKILLS	P	REMOVED
4	BENCH CHECKED - NRTS - LACK OF PARTS	Q	INSTALLED
5	BENCH CHECKED - NRTS - SHOP BACKLOG	R	REMOVE AND REPLACE
6	BENCH CHECKED - NRTS - LACK OF TECHNICAL DATA	S	REMOVE AND REINSTALL
7	BENCH CHECKED - NRTS - EXCESS TO BASE REQUIREMENTS	T	REMOVED FOR CANNIBALIZATION
8	FOR FUTURE USE	U	REPLACED AFTER CANNIBALIZATION
9	BENCH CHECKED - CONDEMNED	V	CLEAN
E	FOR FUTURE USE	W	DEFERRED
F	REPAIR	X	TEST - INSPECT - SERVICE
G	REPAIR AND/OR REPLACEMENT OF MINOR PARTS, HARDWARE, AND SOFTGOODS (SEALS GASKETS, ELECTRICAL CONNECTORS, FITTINGS, TUBING, HOSE, WIRING, FASTENERS, VIBRATION ISOLATORS, BRACKETS, ETC.)	Y	TROUBLE SHOOT
		Z	CORROSION TREATMENT. INCLUDES CLEANING, TREATING, PRIMING, AND PAINTING OF CORRODED ITEMS

Source: Work Unit Code Manual for the F-111 (T.O. 1F-111A-06).

4.3 DATA SOURCES

Data collection for the F-111 Category II Testing at Edwards AFB is an AFSC adaptation of the procedure outlined in the Air Force Maintenance Management Manual (AF Manual 66-1). This particular data acquisition procedure is known as the 258 Data System and is characterized by AFSC Forms 258 and 258-4. AFSC Form 258 is a single copy form used for recording maintenance actions as described in Section 4.2 above and likewise for the four copy AFSC Form 258-4. The format of these forms are identical. In order to keep track of all maintenance tasks Copy One of the 258-4 is used to record removal and replacement of all repairable/recoverable items, including time change items, or removal accomplished separately from replacement action. Copy Two is used as a control for items being processed within the maintenance shop to report repair cycle information. Copy Three is used to report bench check. Copy Four is used to report repair action when accomplished separately from bench check and also serves as a reparable tag.

Coding for the 258 Forms is obtained from the Air Force Technical Order 1F-111A-06 (for the F-111 aircraft), i.e., the "Work Unit Code Manual." This manual contains "When Discovered" codes, Table 4.3.1, "How Malfunctioned" codes, Table 4.3.2, and "Work Unit" codes, Tables 4.3.3 - 4.3.5. All these codes are common to all Air Force activities and operational equipment, except "Work Unit" codes. The latter codes are unique to each weapons system. They are identified in specific Work Unit Code Manuals peculiar to each weapon system. These codes are described in more detail below.

The management data blocks of the 258 system forms (Figure 2.3.1) used for this study are:

(1) Report Number (PPRN): This is a unique serial number preprinted on each form.

(2) Original Report Number (ORN): This entry is the primary key to track and tie together a complete chain of events. From the initial report, each subsequent line or shop action should reflect the same ORN, until all degraded items connected with the original report are either returned to service or condemned.

Table 4.3.1. When Discover Codes Used for Maintenance Activities for the F-111

Code	Description	Code	Description
A	BEFORE FLIGHT-ABORT-AIRCREW	N	GROUND ALERT-DEGRADED
B	BEFORE FLIGHT-NO ABORT-AIRCREW	P	FUNCTIONAL CHECK FLIGHT
C	IN-FLIGHT ABORT	Q	SPECIAL INSPECTION
D	IN-FLIGHT NO ABORT	R	QUALITY CONTROL CHECK
E	AFTER FLIGHT-AIRCREW	S	DEPOT LEVEL MAINTENANCE
F	BETWEEN FLIGHTS-GROUND CREW	T	DURING SCHEDULED CALIBRATION
G	GROUND ALERT-NOT DEGRADED	U	NON-DESTRUCTIVE INSPECTION. INCLUDES OPTICAL, PENETRANT, MAGNETIC PARTICLE, RADIOGRAPHIC, EDDY CURRENT, ULTRASONIC, SPECTROMETIC OIL ANALYSIS, ETC.
H	BASIC POSTFLIGHT INSPECTION	V	DURING UNSCHEDULED CALIBRATION
J	PREFLIGHT INSPECTION	W	IN-SHOP REPAIR AND/OR DISASSEMBLY FOR MAINTENANCE
L	DURING TRAINING OR MAINTENANCE ON EQUIPMENT UTILIZED IN A TRAINING ENVIRONMENT (USE ONLY FOR CLASS II TRAINING EQUIPMENT). THIS CODE SHOULD BE USED WHEN RECORDING MAINTENANCE OR DISCREPANCIES ON CLASS II TRAINERS	X	ENGINE TEST STAND OPERATION
M	PHASED INSPECTION	Y	UPON RECEIPT OR WITHDRAWAL FROM SUPPLY STOCKS

Source: Work Unit Code Manual for the F-111 (T.O. 1F-111A-06).

Table 4.3.2. How Malfunctioned Codes Used for Maintenance Activities for the F-111

Code	Description	Code	Description
001	GASSY	103	ATTACH DISPLAY MALFUNCTION
003	OPEN FILAMENT OR TUBE CIRCUIT	105	LOOSE OR DAMAGED BOLTS, NUTS, SCREWS, RIVETS, FASTENERS, CLAMPS, OR OTHER COMMON HARDWARE
004	LOW GM OR EMISSION	106	MISSING BOLTS, NUTS, SCREWS, RIVETS, FASTENERS, CLAMPS OR OTHER COMMON HARDWARE
007	ARCING, ARCED	108	BROKEN, FAULTY OR MISSING SAFETY OR KEY
008	NOISY	111	BURST OR RUPTURED
009	MICROPHONIC	116	CUT
010	POOR OR INCORRECT FOCUS	117	DETERIORATED
020	WORN, CHAFED OR FRAYED	127	ADJUSTMENT OR ALIGNMENT IMPROPER
028	CONDUCTANCE INCORRECT	130	CHANGE OF VALUE
029	CURRENT INCORRECT	135	BINDING STUCK OR JAMMED
037	FLUCTUATES, UNSTABLE OR ERRATIC	150	CHATTERING
051	FAILS TO TUNE - DRIFTS	158	LAUNCH DAMAGE
064	INCORRECT MODULATION	160	CONTACTS/CONNECTIONS DEFECTIVE
065	HIGH-VOLTAGE STANDING WAVE RATIO	167	TORQUE INCORRECT
070	BROKEN	169	INCORRECT VOLTAGE
080	BURNED OUT OR DEFECTIVE LAMP, METER OR INDICATING DEVICE	170	CORRODED
086	IMPROPER HANDLING	181	COMPRESSION, LOW
088	INCORRECT GAIN	190	CRACKED
092	MISMATCHED - WHEEL HALVES, ELECTRONIC PARTS, ETC.	230	DIRTY, CONTAMINATED OR SATURATED BY FOREIGN MATERIAL
094	NO GAIN OR EMISSION	ETC.	ETC.

Source: Work Unit Code Manual for the F-111 (T.O. 1F-111A-06).

Table 4.3.3. A Sample of Work Unit Codes for Airframe for the F-111

Code	Description
11000	AIRFRAME - FUSELAGE
	NOSE SECTION
11AAA	RADOME
11AAB	LATCH ASSY, RADOME
11AAC	HINGE ASSY, RADOME
11AAD	ROD ASSY, RADOME LOCK
11AAE	FRAME
11AAF	BULKHEAD
11AAG	FLOOR
11AAH	SKIN
11AAJ	FAIRING
11AAK	COVERS, ACCESS
11AA9	NOC
	NOSE SECTION DOORS
11ABA	DOOR, FWD EQUIPMENT BAY FWD L.H. (1101)
11ABB	DOOR, FWD EQUIPMENT BAY FWD R.H. (1201)
11ABC	DOOR, FWD EQUIPMENT BAY AFT L.H. (1102)
11ABD	DOOR, FWD EQUIPMENT BAY AFT R.H. (1202)
11ABE	SUPPORT ASSY, FWD EQUIPMENT BAY DOORS
11ABF	DOOR, OXYGEN FILLER (1204)
11AB9	NOC
	CENTER SECTION
11ACA	FRAME
11ACB	BULKHEAD
11ACC	FLOOR
11ACD	SKIN
11ACE	LADDER, CREW ENTRANCE
Etc.	Etc.

Source: Work Unit Code Manual for the F-111 (T.O. 1F-111A-06).

Table 4.3.4. A Sample of Work Unit Codes for Hydraulic and Pneumatic Power Supply for the F-111

Code	Description
45000	HYDRAULIC AND PNEUMATIC POWER SUPPLY
45A00	PRIMARY HYDRAULIC POWER SUPPLY
45AAA	PUMP, HYDRAULIC (TCI)
45AAB	VALVE, HYDRAULIC FIREWALL SHUTOFF
45AAC	FILTER ASSY, HYDRAULIC CASE DRAIN
45AAD	COOLER ASSY, PRIMARY HYDRAULIC (TCI)
45AAE	VALVE, AIR EJECTOR COOLER
45AAF	FILTER ASSY, DUAL PRESSURE (TCI)
45AAG	VALVE, SYSTEM RELIEF
45AAH	SWITCH, LOW PRESSURE
45AAJ	TRANSMITTER, HYDRAULIC PRESSURE
45AAK	INDICATOR, HYDRAULIC PRESSURE
45AAL	ACCUMULATOR, DAMPER SERVO (TCI)
45AAM	ACCUMULATOR, HORIZONTAL STABILIZER (TCI)
45AAP	GAGE, ACCUMULATOR
45AAQ	DRIER, AIR CHEMICAL
45AA9	NOC
45AB0	RESERVOIR ASSY, PRIMARY HYDRAULIC (TCI)
45ABA	THERMOMETER, DIRECT READING
45ABB	FILTER ASSY, RETURN
45ABC	VALVE, BYPASS
45ABD	SUPPORT ASSY
45ABE	VALVE, RESERVOIR HYDRAULIC RELIEF
45ABF	VALVE, RESTRICTOR CHECK PNEUMATIC
Etc.	Etc.

Source: Work Unit Code Manual for the F-111 (T.O. 1F-111A-06).

Table 4.3.5. A Sample of Work Unit Codes for Bombing Navigation for the F-111

Code	Description
73000	BOMBING NAVIGATION
73A00	INERT BOMB NAVIGATION SYSTEM AN/AJQ20
73AA0	STABILIZATION PLATFORM MX-6767/AJQ20
73AAA	MODULE, TEMPERATURE CONTROL
73AAB	MODULE, ROLL/PITCH SERVO
73AAC	MODULE, PLATFORM AMPLIFIER
73AAD	MODULE, VELOCITY
73AAE	MODULE, ALIGN
73AAF	MODULE, LATITUDE REPEATER
73AAG	MODULE, POWER SUPPLY
73AAH	MODULE, ACCELERATION INTEGRATOR
73AAJ	MODULE, PLATFORM
73AA9	NOC
73AB0	NAVIGATIONAL COMPUTER CP812/AJQ20
73ABA	MODULE, FRONT PANEL
73ABB	MODULE, LATITUDE
73ABC	MODULE, LONGITUDE
73ABD	MODULE, POWER SUPPLY
73ABE	MODULE, HEADING
73ABF	MODULE, GROUND TRACK AND GROUNDSPEED
73ABG	MODULE, RANGE
73ABH	MODULE, GLIDE AND DIVE
73ABJ	MODULE, WIND
73ABK	MODULE, OFFSET
73ABL	MODULE, SELF-TEST
73ABM	MODULE, SLANT RANGE
Etc.	Etc.

Source: Work Unit Code Manual for the F-111 (T. O. 1F-111A-06).

The PPRN from the initial report should be transcribed to the ORN block of the initial report and each subsequent 258 series form. Generation of additional reports is necessary when more than one item is worked on, or when delays in maintenance action occur. The same ORN should appear on every copy of every report stemming from the original discrepancy. This number may be transcribed to the ORN block from previous reports or from historical records. In order to fix ideas consider the following example.

(a)	The right turbo engine failed to operate, and trouble shooting has started.	PPRN 1234	ORN 1234
(b)	The center section access covers were removed to permit inspection of engine.	PPRN 2345	ORN 1234
(c)	The right turbo engine was removed, and replaced with a new, like engine.	PPRN 3456	ORN 1234
(d)	The access covers were reinstalled. The new engine was run up, checked and found satisfactory.	PPRN 6543	ORN 1234
(e)	The engine removed from the aircraft was bench checked, and a compressor rotor found damaged.	PPRN 4567	ORN 1234
(f)	The front compressor rotor was removed and replaced by a serviceable like item.	PPRN 4567	ORN 1234
(g)	The engine was reassembled, bench checked and found serviceable.	PPRN 4567	ORN 1234
(h)	The compressor rotor was bench checked, found damaged beyond repair and condemned.	PPRN 6789	ORN 1234

The eight maintenance actions above make up one complete chain of events, all tied together with ORN 1234.

(3) Item Identification: This identifies the weapons system or end item on which work is required or being performed. Usually this is aircraft type, i.e., F-111A.

(4) Serial Number: This is an Air Force or manufacturers serial number of the item identified above. Usually this is an aircraft tail number, i.e., 65-5701.

(5) Time/Cycles or Miles: This reflects the time, to the nearest hour, cycles or miles of the end item (usually the aircraft listed above). This information is transcribed from historical records or other data sources, such as running time meters.

(6) When Discovered Time: This is the day, month, year, and hour (to the nearest five minutes) when the discrepancy was discovered. Example: 03/08/67/1710 for 3 August 1967 at 1710 hours.

(7) Date This Report: The day, month, and year on which the job is performed. The form should be initiated the same day that work was accomplished.

(8) When Discovered Code: This is the approximate code from the Work Unit Code manual that identifies when the defect or need for maintenance action was discovered (see Table 4.3.1).

(9) Failed Item Manufacturer: This is an alpha-numeric code identifying the manufacturer. The code is extracted from Air Force supply manuals or the Illustrated Parts Breakdown of the failed item.

(10) Failed Item Noun: This is the noun which best describes the failed item as indicated in the Work Unit Code Manual.

(11) Failed Item Serial Number: This is the manufacturers serial number of the equipment or component being removed, obtained from the item data plate.

(12) Failed Item Time Cycles or Miles: This is time to the nearest hour, cycles, or miles of the failed item. This is in addition to the Time, Cycles or Miles listed in (5) above. This entry is for the failed item, while the entry listed in (5) is for the aircraft or other end item from which it is removed.

(13) Failed Item Part Number: This is the part number as it appears on the attached data plate, or from the parts catalog. Care in recording this number is necessary, as this is another key in tracking a complete chain of maintenance events.

(14) Work Unit Code (WUC): The work unit code is also a prime key to tracking maintenance history.

The Work Unit Code system is an Air Force-wide technique to encode specific hardware items to facilitate data collection. Analysis of these data elements may be used to evaluate a particular maintenance policy or for historical and logistic purposes. The utility of the Work Unit code system is that it assigns a unique code to each component or assembly within the weapon system, regardless of manufacturer. However, these codes are not universal since there are separate manuals for each aircraft and missile type. Each manual has its own technical order number, the first part of which reflects the equipment for which it was designed. The last part of the number is usually -06; for example, the manual for the F-111A is Technical Order (T.O. 1F-111A-06). They are generally referred to as the "dash six manuals." Three pages from T.O. 1F-111A-06 WUC manual are shown in Tables 4.3.3 through 4.3.5. Only three systems are reflected in the above tables, the airframe, the hydraulic and pneumatic power supply, and the bombing/navigational equipment. A list of the other systems covered by the -06 manual are shown in Table 4.3.6.

With reference to Tables 4.3.3 through 4.3.5, the first two digits of each Work Unit Code designate a system. For example, Airframe is identified by system Code 11, Hydraulic and Pneumatic Power Supply is identified by system Code 45, and Bombing/Navigational equipment is identified by system Code 73. The third indenture or digit of the five digit code identifies a subsystem. The fourth and fifth digits designate an assembly and/or specific component. For example, consider work unit code 11AAB from Table 4.3.3. The system code 11 identifies the airframe. The subsystem code 11A identifies the nose section. The radome, a sub-indenture of the nose section, is coded 11AA. The specific component identified by Work Unit Code 11AAB, is the radome latch assembly which is part of the nose section of the airframe. As a second example, consider Work Unit Code 45ABC from Table 4.3.4. This is a bypass valve, which is part of the primary hydraulic reservoir assembly.

Table 4.3.6: Subsystem Identification Codes for the F-111

SYSTEM CODE	DESCRIPTION
01	GROUND HANDLING AND SERVICE
02	AIRCRAFT CLEANING
03	"LOOK" PHASE OF SCHEDULED INSPECTIONS
04	SPECIAL INSPECTIONS
05	AIRCRAFT AND INSTALLED ENGINE STORAGE
06	GROUND SAFETY
07	PREPARATION AND/OR MAINTENANCE OF AIRCRAFT RECORDS
08	SPECIAL WEAPONS HANDLING (MUNITIONS MAINTENANCE SQUADRON FACTIONS)
09	SHOP SUPPORT
11	AIRFRAME
12	COCKPIT AND FUSELAGE COMPARTMENTS
13	LANDING GEAR
14	FLIGHT CONTROL
16	ESCAPE CAPSULE
23	TURBO JET ENGINE
41	AIR CONDITIONING, PRESSURIZATION, AND SURFACE ICE CONTROL
42	ELECTRICAL POWER SUPPLY
44	LIGHTING SYSTEM
45	HYDRAULIC AND PNEUMATIC POWER SUPPLY
46	FUEL SYSTEM
47	OXYGEN SYSTEM
49	MISCELLANEOUS UTILITIES
51	INSTRUMENTS
52	AUTOPILOT
61	HF COMMUNICATIONS
63	UHF COMMUNICATIONS
64	INTERPHONE
65	IFF
71	RADIO NAVIGATION
73	BOMBING NAVIGATION
74	FIRE CONTROL SYSTEM
75	WEAPONS DELIVERY
76	ELECTRONIC COUNTERMEASURE
96	PERSONNEL EQUIPMENT
97	EXPLOSIVE DEVICES AND COMPONENTS

Source: Work Unit Code Manual for the F-111 (T.O. 2F-11A-06)

(15) How Malfunctioned Code (HOW MAL): This is a three digit numerical code that best describes the nature of malfunction or action required on the assembly or component identified by the Work Unit Code. These codes are universal throughout the Air Force. Each code has identical meaning, regardless of weapons system (See Table 4.3.2).

(16) Installed Item Noun: Similar to failed item noun. Applicable to the assembly or component installed.

(17) Installed Item Serial Number: The serial number from the data plate of the assembly or component being installed.

(18) Installed Item Time/Cycles or Miles: Time to the nearest hour, cycles or miles extracted from historical records.

(19) Installed Item Part Number: The part number of the item being installed is taken from its data plate, or parts catalogs. This number will not necessarily be the same as the Failed Item Part Number, due to other manufacturer, or later model components.

The AFSC speciality code is also required. This is a numeric code universally used throughout the Air Force. The code breaks down to career field (such as aircraft electronics), career field subdivision (such as communication), skill level, i. e., apprentice, mechanic, technician, and supervisor. This code is entered to reflect the personnel who performed the work or corrected the malfunction. Finally, start and stop time is the clock time to the nearest five minutes when the work begin and when the work was either completed or delayed.

Several other blocks of data are contained within the 258 series forms, but are not utilized in the performance of this study.

4.4 MISSION DEBRIEFING DATA ELEMENTS

The management data blocks of the F-111 Mission Debriefing Form AFFTC 0-294 (Figures 2.3.3 and 2.3.4 of Section 2) that are used for this study are the following:

(1) Mission Number: The mission is identified by a serialized numeric plus the aircraft code letter. For example: 014H is the 14th Category II flight on aircraft 773.

(2) Aircraft Number: The last three digits of the Air Force Serial Number (tail number).

(3) Date: Day, month, and year the flight was completed.

(4) Type Mission: This is a three digit code for the mission performed, such as ferry, loiter, or intercept.

(5) Actual Duration: Hours and minutes of the completed mission.

(6) LH and RH AB time: This is the hours and minutes the right or left hand afterburners were used.

(7) Number of Landings: Total number of landings during the entire mission, including touch and go landings.

(8) Wing Sweeps: Number of times wings were swept from forward to delta position.

(9) Card Number: This is a 4000 series number assigned to each function, i.e.:

Card Number	System
4001	Airframe
4028	Fuel Transfer
4096	Cabin Air Conditioning
4135	Terrain Following Radar

There are a total of 180 of the 4000 functional codes.

(10) Phase of Flight: There are twelve phases of flight making up a matrix for each of the 180 functional codes. They include Pre-start inspections, take-off and acceleration, cruise and landing phases.

An entry is made for each phase of the total mission using the alpha characters within functional code:

S	Satisfactory
D	Degraded performance (Equipment still usable)
F	Failure
K	Uncleared Discrepancy

It is assumed that when a matrix block is left blank, the equipment was not checked or used during that phase of flight. For example, these functions may have behaved in the following manner:

Card Number	System	Pre-Start	Taxi	Take Off	Cruise	Landing	Discrepancy
4060	Flight Control, Yaw	S		S	S	D	Controls Stiff
4084	Intercom	S	S		F	F	Mike broken
4105	Instruments	K	D	D	D	D	Air Temp. Indicator glass cracked

4.5 PROBLEMS WITH THE 258/MISSION DEBRIEFING DATA SYSTEM

The concept of designing and implementing a general purpose data base for weapon systems effectiveness analysis is very complex. A variety of problems are expected when an experimental data system is implemented. Usually, data system problems identify inconsistencies in the initial design and their solutions tend to suggest ways for improving the system. In this section, some of the problems encountered while using the 258/Mission Debriefing Data System are identified.

It should be recognized that the 258 Data System and the Mission Debriefing Data System are dissimilar but supplemental, since the 258 data are hardware oriented while the debriefing data are functionally oriented. Thus, a one to one cross reference is impossible. Moreover, a component identified by its Work Unit Code may effect several functions within the weapon system. Similarly, a failure of one function often requires trouble-shooting and replacement of several hardware components, each having its own Work Unit Code, before the function is restored to its operating state. Thus, if the Original Report Number (ORN) is not entered correctly on each 258 Form which is related to the above maintenance tasks, then the tracking of all tasks associated with a particular maintenance event will be very difficult. Another area of difficulty is the inconsistency between ACTAK, HOW MAL Codes and Corrective Action Narrative. Other areas of difficulty are unidentifiable Work Unit Codes, inconsistencies between stop and start times and missing information.

Obviously, many of the above problems could be resolved through more adequate training of personnel in order to acquaint them with the proper record completion procedures. Finally, maintenance personnel must understand the importance of correct entries in the data system, since otherwise the data will be meaningless and weapon system effectiveness analysis will be impossible.

5.0 ANALYTICAL PROBLEMS FOR F-111 CRITICAL LRU

A weapon system must be reliable and maintainable in order to be an effective weapon system as far as mission requirements are concerned. Since the military must plan for an immediate availability of weapon systems in case of a national emergency, delays due to weapon system malfunction or failure are not desirable. Thus, it is now realized that the maintainability of a weapon system is at least as important as its reliability. Hence, maintenance policies have been introduced to assure the required availability of weapon systems. A maintenance policy which appears to satisfy the immediate availability for weapon systems is one which requires block replacement, i.e., when a part fails the entire unit containing that part is replaced and the removed unit is sent off site (to maintenance shop or depot) for repair. In Air Force terminology such a unit is called a Line Replaceable Unit (LRU). Obviously, such a policy reduces the down time of the weapon system provided the necessary spares are available. In reality, the actual maintenance and spares requirements cannot be predicted in advance. Thus, it becomes necessary to estimate these requirements from observations made on the weapon system. But in many situations it is impossible to obtain accurate estimates due to insufficient data. On the other hand, if sufficient data are available certain analytical problems must be solved in order to obtain meaningful maintainability information from such data.

With the cooperation of the F-111 Provisioning Team, General Dynamics Corporation, Fort Worth, Texas, and the Air Force Logistic Command (AFLC), McClellan AFB, Sacramento, California, the following four problems were identified.

(1) The distribution of maintenance events for eleven LRU's on the F-111 that AFLC considered to be critical.

(2) The relationship between replacement and failure indications for each Critical LRU.

(3) The estimated replacement for each Critical LRU for ten mission types specified for the F-111.

(4) The evaluation of current replacement estimates for each Critical LRU.

In this report solutions are provided for the above problems based on the F-111 Category II Test Data from Edwards AFB, California.

5.1 IDENTIFICATION OF F-111 CRITICAL LRU'S AND THE CURRENT PROCUREMENT BASIS

If the availability requirements for the F-111 are to be satisfied, the maintenance policy for this aircraft must minimize down time due to malfunction and failure of system components, etc. Thus, in order to assure with high probability that the F-111 will meet its availability requirements accurate estimates of the spares requirement for this aircraft must be available. In this regard, eleven Critical LRU's for the F-111 were identified by AFLC for analysis. These units are listed in Table 5.1.1 with their respective cost and current K-value (maintenance factor). The K-value given in Table 5.1.1 is the current estimated replacements per 100 flying hours by AFLC. Thus, each LRU under consideration is provisioned on the basis of its K-value. If the K-value for a particular LRU is too small, then that unit will be under provisioned which reduce the chance of satisfying the availability requirements. On the other hand, if the K-value for a particular LRU is too large, then that unit will be over provisioned which requires the expenditure of unnecessary funds. Thus, it is important to estimate the probability distribution of K for each LRU given the mission profile so that the risk of not satisfying the spares requirement can be determined. This particular problem is considered in Section 5.4.

5.2 THE DISTRIBUTION OF MAINTENANCE EVENTS FOR EACH CRITICAL LRU

It was shown in SAMSO Report 67-12 that man-hours-to-repair the actual hardware as well as time to failure or time between failure for subsystems of the F-111 Category II Test Data can be fitted to certain standard probability distributions automatically. In this section, the distribution of the total time associated with maintenance events for Critical LRU's of interest from the F-111 Category II Test Data is considered.

<u>Definition 5.2.1</u>: <u>The administrative and technical activities associated with the restoration of a device, to its operating state is said to be a maintenance event.</u>

Table 5.1.1. F-111 Critical Line Replaceable Units and Current Replacement Estimates

Part Number	Work Unit Code	Description	Cost Per Unit	K-Value
1. 852D750G1	WUC 74AAB	AMPLIFIER ASSEMBLY-LEAD AND LAUNCH COMPUTING	$ 9,178	0.625
2. 204530-2-1	WUC 41ABA	COOLING TURBINE	$ 5,400	0.100
3. HG 7092A2	WUC 73CAO	TRANSMITTER/RECEIVER	$ 6,796	0.750
4. 500113-10	WUC 73DFO	SYNCHRONIZER-TRANSMITTER	$ 4,987	0.500
5. 7635519G4	WUC 73BDO	MODULATOR, RECEIVER-TRANSMITTER	$ 53,125	1.333
6. 1819671-6	WUC 52BAA	COMPUTER, CENTRAL AIR DATA	$ 42,560	1.000
7. 12 C 1006-811	WUC 52BBR	MACH ASSEMBLY, MAXIMUM SAFE	$ 5,000	0.666
8. 230 E 125G11	WUC 52ACA	COMPUTER, FLIGHT CONTROL YAW	$ 20,560	0.875
9. 660000	WUC 73AAO	STABILIZATION PLATFORM	$ 91,965	2.000
10. 12 C 1154-817 12 C 1154-827	WUC 52ADA	FEEL TRIM ASSEMBLY	$ 8,850	1.333
11. 658402	WUC 73ABO	NAVIGATIONAL COMPUTER (CP812/AJQ-20)	$100,377	2.000

Source: Air Force Logistics Command, McClellan AFB, Sacramento, California.

Obviously, a maintenance event may consist of a series of activities such as repair, test, or preventive maintenance. In this section, the results of problem (1) are given. Details and definitions are given in Appendix II so that the interested reader can apply this type of analysis to similar problems of interest. For convenience, several of the basic definitions are given below.

Let T denote active hours, elapsed hours or man-hours to restore a particular LRU to its operating state. When T includes trouble-shooting time, delay time due to shortage of parts, transportation, or other nonrelated factors, as well as the actual time to restore the LRU to its operating state, then T denotes the elapsed hours associated with that maintenance activity. On the other hand, when T includes only the actual hours to restore the LRU to its operating state, then T denotes the active hours associated with that maintenance activity. Finally, if T is the time required for maintenance personnel to restore the LRU to its operating state, then, obviously, T denotes the man hours associated with that maintenance activity.

To fix ideas let $t_1, t_2, \ldots, t_n$ denote the history of active hours, or etc., to restore a particular LRU of the F-111 to its operating state. Let $t_{(1)}, t_{(2)}, \ldots, t_{(n)}$ denote the ordered t_j's, then by definition

$$S_n(t) = \begin{cases} 0: & \text{If } t < t_{(1)} \\ \frac{k}{n}: & \text{If } t_{(k)} < t \leq t_{(k+1)};\ k = 1, 2, \ldots, n-1 \\ 1: & \text{If } t > t_{(n)} \end{cases} \tag{5.2.1}$$

is the sample distribution function for the above history of active hours, etc. In (5.2.1) k denotes the number of $t_{(j)}$'s within the range $(t_{(1)}, t_{(k)})$. Schematically, the sample distribution function for five ordered $t_{(j)}$'s may be represented by the step function in Figure 5.2.1.

From a theoretical point of view any function F with the following properties is said to be a distribution function

(i) $F(-\infty) = 0$,

(ii) $F(t)$ is non-decreasing for $-\infty < t < \infty$,

(iii) $F(\infty) = 1$.

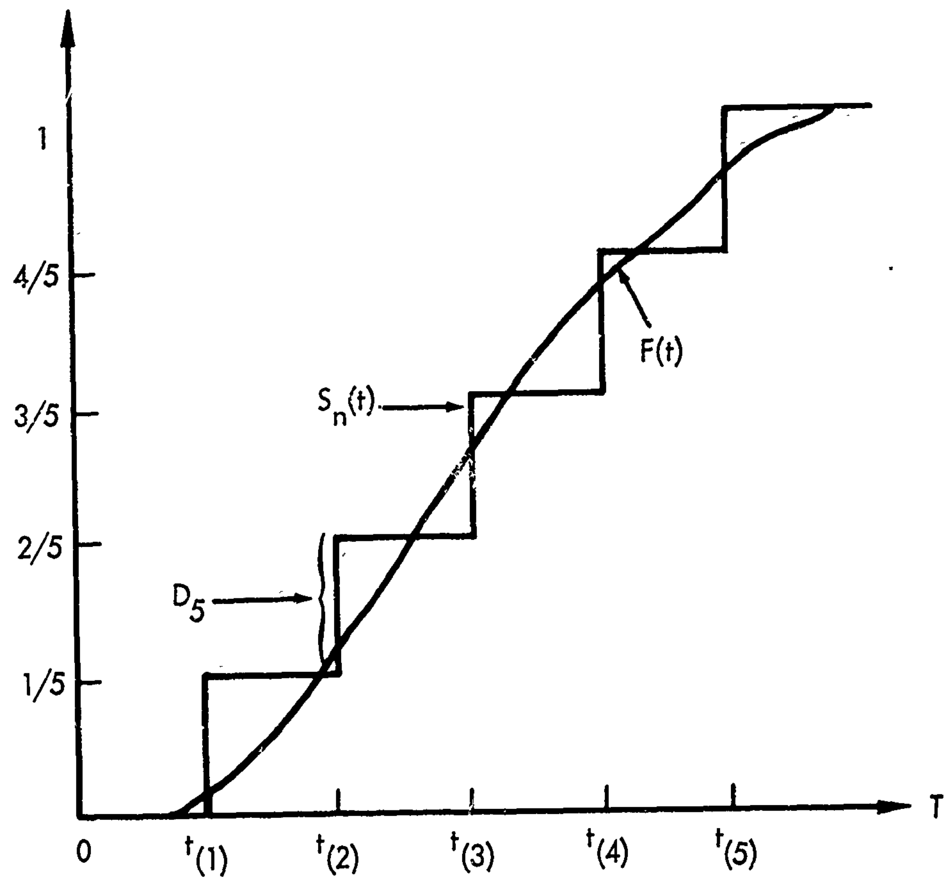

Figure 5.2.1: The representation of a sample distribution function for a sample of five distinct points and a theoretical distribution function.

In the continuous case a random variable T may be defined in terms of its density function. Hence, any function f with the properties

$$\text{(i)} \quad f(t) \geq 0, \qquad -\infty < t < \infty$$

$$\text{(ii)} \quad \int_{-\infty}^{\infty} f(t)\,dt = 1$$

can serve as a density function of the continuous random variable T and we define

$$F(t) = \int_{-\infty}^{t} f(x)\,dx = \Pr\,(T < t) \tag{5.2.2}$$

to be distribution function of T. Obviously, $t \geq 0$ since T is time. Since the functions which characterize the log normal, exponential and Weibull distributions satisfy the above requirements, the following definitions are given.

Definition 5.2.1 (Log-Normal): If the random variable T is such that $T' = \log_e (T)$ has the density

$$f(t' \mid \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2\right\} \quad , \tag{5.2.3}$$

$-\infty < t' < \infty$, where μ and σ^2 denote the mean and variance of T', then T is said to be log-normal with mean

$$m = E(T) = \exp(\mu + \sigma^2/2) \quad , \tag{5.2.4}$$

and variance

$$VAR(T) = \exp\left\{2(\mu + \sigma^2)\right\} - \exp\left\{2\mu + \sigma^2\right\} \quad . \tag{5.2.5}$$

Definition 5.2.2 (Exponential): A random variable T is said to be distributed as an exponential distribution with parameter λ if its density is

$$f(t \mid \lambda) = \lambda \exp(-\lambda t) \quad . \qquad (5.2.6)$$

Definition 5.2.3 Weibull: A random variable T is said to be distributed as a Weibull distribution with β and λ^* if its density is

$$f(t \mid \beta, \lambda^*) = \beta \lambda^* t^{\beta-1} \exp(-\lambda^* t^\beta) \quad . \qquad (5.2.7)$$

In Appendix II the Kolmogorov-Smirnov statistic is used to compare $S_n(t)$ with the above probability distributions in order to determine which family of probability distributions $S_n(t)$ is most likely to be a member of. The Kolmogorov-Smirnov statistic is denoted by the quantity

$$D_n = \sup_t \mid S_n(t) - F(t) \mid \qquad (5.2.8)$$

which is the maximum vertical distance between the graphs of F(t) and $S_n(t)$ over the range of possible t values (see Figure 5.2.1).

The results are as follows:

(1) Shop active, elapsed and man hours for Critical LRU - Transmitter/Receiver, WUC 73CAO, are more likely to be distributed as a log-normal distribution whose logarithm is normally distributed with mean $\overline{t'} = 1.40$ and variance $s^2_{t'} = 1.17$, $\overline{t'} = 2.11$ and $s^2_{t'} = 4.28$, $\overline{t'} = 1.89$, and $s^2_{t'} = 1.33$ respectively (see Table 1 and Figures 1 through 9 in Appendix II).

(2) Line active, elapsed and man hours for Critical LRU - Transmitter/Receiver, WUC 73CAO, are more likely to be distributed as a log-normal distribution whose logarithm is normally distributed with mean $\overline{t'} = 1.05$ and variance

$s^2_{t'} = 0.87$, $\bar{t}' = 2.35$ and $s^2_{t'} = 2.02$, $\bar{t}' = 1.62$ and $s^2_{t'} = 1.76$ respectively (see Table 2 and Figures 10 through 18 in Appendix II).

(3) Shop active and elapsed hours for critical LRU - Modulator, Receiver/Transmitter, WUC 73BDO, are more likely to be distributed as a log-normal distribution whose logarithm is normally distributed with mean $\bar{t}' = 1.56$ and variance $s^2_{t'} = 1.30$, $\bar{t}' = 1.91$ and $s^2_{t'} = 1.74$ respectively. However, shop man hours for the above LRU are more likely to be disbributed as an exponential distribution with parameter $\hat{\lambda} = 0.0685$ (see Table 3 and Figures 19 through 27 in Appendix II).

(4) Line active, elapsed and man-hours for Critical LRU - Modulator, Receiver/Transmitter, WUC 73BDO, are more likely to be distributed as a log-normal distribution whose logarithm is normally distributed with mean $\bar{t}' = 1.07$ and variance $s^2_{t'} = 0.32$, $\bar{t}' = 2.62$ and $s^2_{t'} = 2.52$, $\bar{t}' = 1.94$ and $s^2_{t'} = 0.34$ respectively (see Table 4 and Figures 28 through 36 in Appendix II).

(5) Shop active and man hours for Critical LRU - Stabilization Platform, WUC 73AAO are more likely to be distributed as a Weibull distribution with parameters $\hat{\beta} = 1.1430$ and $\hat{\lambda}^* = 0.0601$, $\hat{\beta} = 1.0710$ and $\hat{\lambda}^* = 0.0334$ respectively. However, shop elapsed hours for the above LRU are more likely to be distributed as a log-normal distribution whose logarithm is normally distributed with mean $\bar{t}' = 3.12$ and variance $s^2_{t'} = 4.42$ (see Table 5 and Figures 37 through 45 in Appendix II).

(6) Line active and elapsed hours for Critical LRU - Stabilization Platform, WUC 73AAO are more likely to be distributed as a log-normal distribution whose logarithm is normally distributed with mean $\bar{t}' = 1.44$ and variance $s^2_{t'} = 0.67$, $\bar{t}' = 2.74$ and $s^2_{t'} = 2.54$ respectively. However, line man hours for the above LRU are more likely to be distributed as

a Weibull distribution with parameters $\hat{\beta}$ = 1.3700 and $\hat{\lambda}^*$ = 0.0313 (see Table 6 and Figures 46 through 54 in Appendix II).

(7) Shop active hours for Critical LRU - Navigational Computer CP812/AJQ-20, WUC 73ABO, are more likely to be distributed as an exponential distribution with parameter $\hat{\lambda}$ = 0.1267. But here a Weibull distribution with parameters $\hat{\beta}$ = 1.1600 and $\hat{\lambda}^*$ = 0.0887 fits the data equally well. However, shop elapsed hours for the above LRU are more likely to be distributed as a log-normal distribution whose logarithm is normally distributed with mean $\overline{t'}$ = 1.95 and variance $s^2_{t'}$ = 2.98. Finally, man hours for the above LRU are more likely to be distributed as a Weibull distribution, with parameters $\hat{\beta}$ = 1.1760 and $\hat{\lambda}^*$ = 0.0351 (see Table 7 and Figures 55 through 62 in Appendix II).

(8) Line active and man hours for Critical LRU - Navigational Computer CP812/AJQ-20, WUC 73ABO, are more likely to be distributed as a Weibul distribution with parameters $\hat{\beta}$ = 1.2280 and $\hat{\lambda}^*$ = 0.1135, $\hat{\beta}$ = 1.1030 and $\hat{\lambda}^*$ = 0.0615 respectively. However, line elapsed hours for the above LRU are more likely to be distributed as a log-normal distribution whose logarithm is normally distributed with mean $\overline{t'}$ = 2.51 and variance $s^2_{t'}$ = 4.00. Here a Weibull distribution with parameters $\hat{\beta}$ = 0.5920 and $\hat{\lambda}^*$ = 0.1259 fits the data equally well (see Table 8 and Figures 63 through 71).

Unfortunately, the remaining Critical LRU's listed in Table 5.1.1 in Section 5.1 had insufficient data for the above type of analysis. However, it is important to recognize that as the F-111 Category II Testing continues the data base upon which this analysis is based will increase, thereby providing additional maintenance history for the above LRU's. Obviously, at that point in time $S_n(t)$ for those LRU's with sufficient data should be recomputed and the above analysis repeated. In fact, such analysis should be carried out periodically in order that the availability and maintainability estimates for the F-111 will be based on the current

field or operational experience of the aircraft. For additional comments see Section 5.6 below and Appendix II.

5.3 THE RELATIONSHIPS BETWEEN REPLACEMENTS AND FAILURE INDICATIONS DURING F-111 CATEGORY II TESTING

It is well known that accurate estimates of the spares requirements for a weapon system cannot be determined unless the failure and replacement histories of the system components can be related. An obvious relationship is a one to one correspondance between a failure indication and a replacement, i.e., for each failure indication a replacement is required. The above relationship between failure indications and replacements, obviously, defines an "upper bound relationship." On the other hand, if no replacement is required for each failure indication, a "lower bound relationship" is indicated. Clearly, the most likely relationship between failure indications and replacements must lie somewhere between these two extremes. In order to find such a relationship, the notion of a failure indication and a replacement must be made more precise.

<u>Definition 5.3.1:</u> <u>Any maintenance activity with a repair type "action taken code" (ACTAK) and a defective type "how malfunctioned code" (HOW MAL) is said to be a failure indication.</u>

For a detailed definition of the above ACTAK and HOW MAL codes see the Air Force Work Unit Code Manual (T.O. 1F-111A-06). Line and shop activities have been separated in the ensuring analysis:

<u>Definition 5.3.2:</u> <u>The exchange of an identical LRU on an aircraft is said to be a line replacement.</u>

In passing it is mentioned that a shop replacement is required when an LRU removed from an aircraft is condemned or transferred off base for repair. In this section a solution is given for problem (2) based on failure indications and line replacements.

Suppose T_i is the time measured in hours that the i^{th} aircraft has been in Category II Testing and let $t \leq T_i$ be a fixed number of hours, where $i = 1, 2, \ldots, N$ aircrafts. Then for the $m_i = T_i/t$ time intervals of t hours or less that the i^{th} aircraft has been in Category II Testing,

consider the number of failure indications and replacements in each of these m_i intervals for a particular LRU. For convenience let $n_j(F)$ and $n_j(R)$ denote the number of failure indications and replacements for the LRU under consideration for the i^{th} aircraft in each of the m_i intervals. Hence, for each time interval the i^{th} aircraft is in Category II Testing a pair of number $(n_j(F), n_j(R))$ are generated for that LRU, where $n_j(R) \leq n_j(F)$ since the number of replacements can never exceed the number of failure indications in any interval. Thus, for any LRU of interest on the i^{th} aircraft a sequence of pairs of numbers $(n_j(F), n_j(R))$, $j = 1, \cdots, m_i$ are generated. Repeating this procedure for each of the N aircrafts, $m_1 + m_2 + \cdots + m_N$ such pairs of numbers are generated for any LRU of interest. When these pairs of values are plotted in the $n(F) \times n(R)$ - plane a scatter plot similar to Figure 5.3.1 is generated. The number associated with each point on Figure 5.3.1 represents the frequency with which that number of failure indications and replacements were observed over each time interval and each aircraft for the Navigational Computer.

Figure 5.3.2 gives the result of fitting a straight line to the data points in Figure 5.3.1. The line $E_1(N(R) | N(F))$ denotes the relationship between replacements and failure indications when the outcome of a failure indication could not be identified as a repair or a replacement. In such situations, it was assumed that a replacement was required when $E_1(N(R) | N(F))$ was computed. On the other hand, when the line $E_2(N(R) | N(F))$ was computed it was assumed that no replacement was required. It should be recognized that the closeness of these two lines gives error bounds on the consistency of the data collection for this particular LRU. Obviously, the line which gives the best estimate of the true relationship for this LRU cannot be determined. However, it is reasonably certain that the best estimate lies between these two lines. The relationships for the remaining LRU's are summarized in Table 5.3.1. Additional comments on this problem can be found in Appendix III.

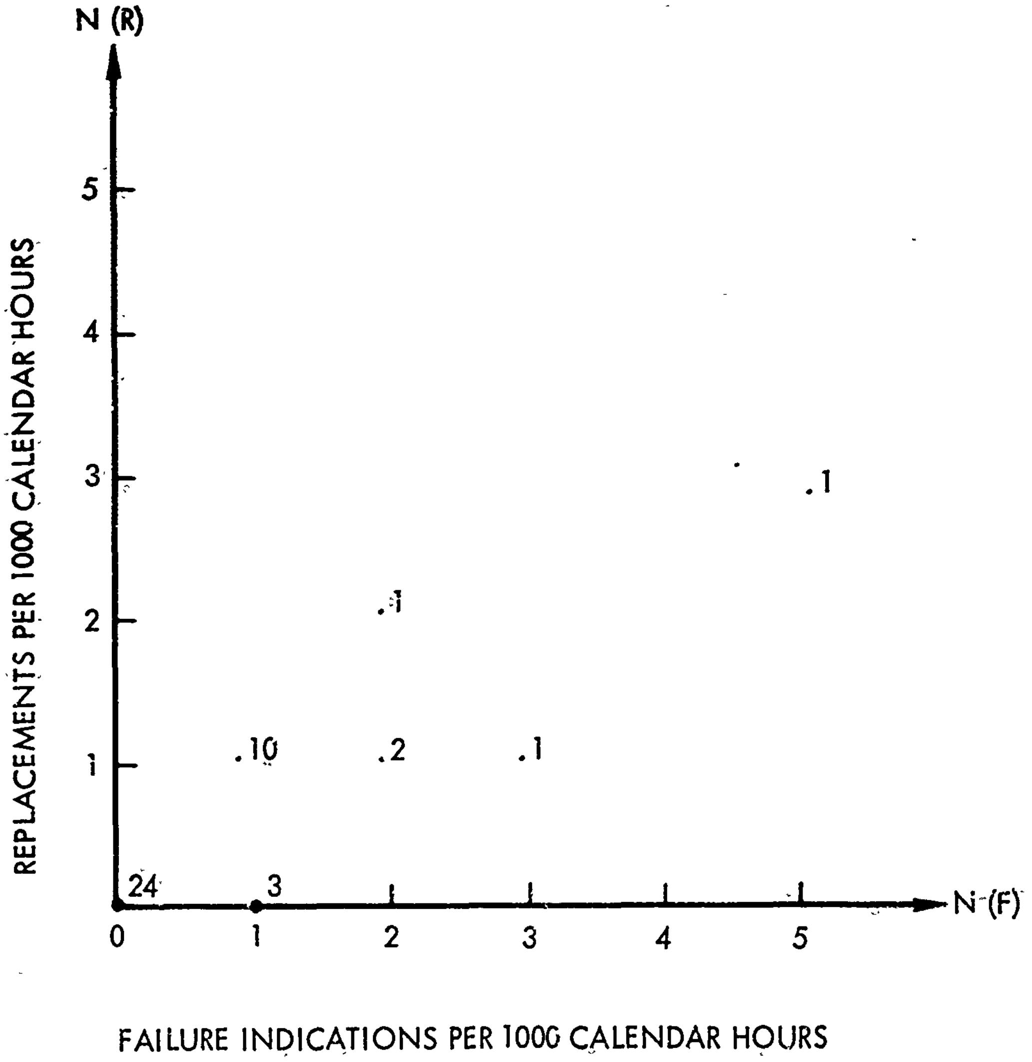

Figure 5.3.1: Scatter plot of the frequency of failure indications and replacements per 1000 calendar hours for Critical LRU-Navigational Computer, WUC 73ABO, for seven F-111's in the Edwards AFB Category II Testing Program.

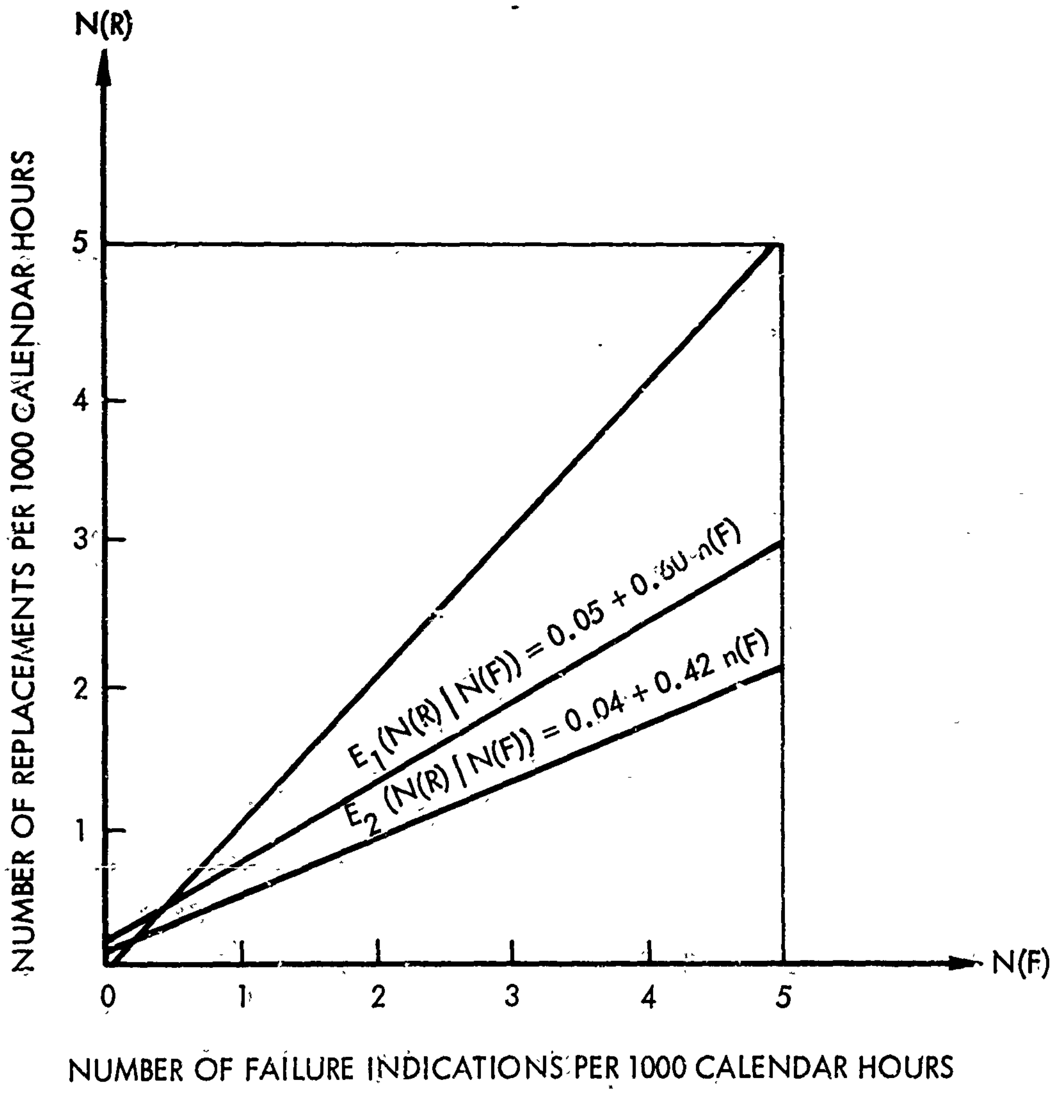

Figure 5.3.2: The relationship between replacements and failure indications per 1000 calendar hours for Critical LRU - Navigational Computer, WUC 73ABO, for seven F-111's in the Edwards AFB Category II Testing Program.

Table 5.3.1 Relating Replacements and Failure Indications for Eleven Critical Line Replaceable Units per 1000 Calendar Hours

Critical LRU	Regression Equation	(Max N(F), Max N(R))
1. AMPLIFIER ASSEMBLY - LEAD AND LAUNCH COMPUTING WUC 74AAB	$E_1(N(R) \mid N(F)) = N(F)$ $E_2(N(R) \mid N(F)) = N(F)$	(1, 1)
2. COOLING TURBINE WUC 41ABA	$E_1(N(R) \mid N(F)) = N(F)$ $E_2(N(R) \mid N(F)) = N(F)$	(1, 1)
3. TRANSMITTER/RECEIVER WUC 73CAO	$E_1(N(R) \mid N(F)) = 0.15 + 0.49\ N(F)$ $E_2(N(R) \mid N(F)) = 0.15 + 0.49\ N(F)$	(8, 4)
4. SYNCHRONIZER-TRANSMITTER WUC 73DFO	$E_1(N(R) \mid N(F)) = N(F)$ $E_2(N(R) \mid N(F)) = -0.01 + 0.90\ N(F)$	(3, 3)
5. MODULATOR, RECEIVER-TRANSMITTER WUC 73BDO	$E_1(N(R) \mid N(F)) = -0.10 + 0.94\ N(F)$ $E_2(N(R) \mid N(F)) = 0.03 + 0.71\ N(F)$	(6, 6)
6. COMPUTER, CENTRAL AIR DATA WUC 52BAA	$E_1(N(R) \mid N(F)) = 0.07 + 0.71\ N(F)$ $E_2(N(R) \mid N(F)) = 0.67\ N(F)$	(3, 2)
7. MACH ASSEMBLY, MAXIMUM SAFE WUC 52BBR	No Data	---
8. COMPUTER, FLIGHT CONTROL YAW WUC 52ACA	$E_1(N(R) \mid N(F)) = N(F)$ $E_2(N(R) \mid N(F)) = N(F)$	(1, 1)
9. STABILIZATION PLATFORM WUC 73AAO	$E_1(N(R) \mid N(F)) = -0.14 + 0.95\ N(F)$ $E_2(N(R) \mid N(F)) = 0.02 + 0.70\ N(F)$	(4, 4)
10. FEEL TRIM ASSEMBLY WUC 52ADA	$E_1(N(R) \mid N(F)) = N(F)$ $E_2(N(R) \mid N(F)) = N(F)$	(2, 1)
11. NAVIGATIONAL COMPUTER (CP812/AJQ-20) WUC 73ABO	$E_1(N(R) \mid N(F)) = 0.05 + 0.60\ N(F)$ $E_2(N(R) \mid N(F)) = 0.04 + 0.42\ N(F)$	(5, 3)

Source: 258 Data System for the F-111, Edwards AFB, California.

5.4 ESTIMATED REPLACEMENTS FOR EACH MISSION TYPE

It is well known that spares requirements for weapon systems whose life span extends beyond a single mission are based on the estimated replacement rate per unit operating time, where time is usually measured in hours. For the F-111 the procurement of spares are based on the estimated replacement rate per 100 flying hours which was denoted in Section 5.1 as the K-value (maintenance factor). Here a different approach is considered. First, it is well known that certain pieces of hardware in a weapon system remain in an operating state during a complete mission even though the mission profile only requires their operation at specified time intervals during the mission. Generally, missions assigned to a particular weapon system varies in time duration, where the time duration of each mission type is known. Obviously, different mission types may require different pieces of hardware. Thus, it is extremely difficult to determine the actual operating time on certain pieces of hardware. On the other hand, it is predetermined whether a particular piece of hardware is required for a given mission type. Moreover, the duration of the mission is specified by its type. Thus, it follows that the replacement rate per mission type can be used as the basis for a procurement policy. In this section the estimated replacements per mission type as well as per 100 flying hours are given.

The reliability/maintainability sample mission profiles for the F-111 Category II Testing at Edwards AFB are given in Table 5.4.1. In general, the analytic problem of estimating replacements per mission type is solved once the regression lines in Table 5.3.1 are available and the mission profiles in Table 5.4.1 are specified. Here the requirement is to redefine the calendar time interval of length t hours of Section 5.3 to be the duration per mission type of Table 5.4.1. Then N(F) and N(R) become the number of failure indications and the number of replacements per mission type respectively. However, it is recognized that N(F) and N(R) are now based on the mission debriefing data elements of the 258/Mission Debriefing Data System. From Section 4.5 it is known that the 258 Data System and the Mission Debriefing Data System are dissimilar, since the 258 data are hardware oriented while the debriefing data are functionally oriented. Thus, when a functional failure indication is observed it is no

Table 5.4.1. Reliability/Maintainability Sample Mission Profiles for the F-111

Mission Type No.	Approximate Hours/Mission	Profile
1	1.0 HOUR	LO - LO - LO - LO
2	1.5 HOURS	LO - LO - LO - LO
3	3.5 HOURS	LO - LO - HI
4	2.5 HOURS	LO - LO - HI
5	1.5 HOURS	LO - LO - HI
6	5.0 HOURS	HI - LO - HI
7	10.0 HOURS	FERRY
8	7.5 HOURS	FERRY
9	3.0 HOURS	LOITER
10	1.0 HOURS	INTERCEPT

Source: Oral Communication, Major T. D. Hill
Edwards AFB Flight Test Center (FTTED).

longer obvious whether a particular LRU has failed or malfunctioned. Hence, N(F) must be estimated and from Section 5.3 $E_1(N(R \mid N(F))$ becomes the estimated number of replacements per mission type.

It should be recognized that the determination of N(F) for a particular LRU for a given mission type is a complex data processing problem. For details, the interested reader is referred to Appendix IV. From Section 5.3 and the estimates of N(F) generated according to Appendix IV the results for each LRU per mission type summarized in Table 5.4.2 were obtained. Finally, if each element in Table 5.4.2 is multiplied by 100 divided by the respective mission duration the estimated replacement for each LRU per 100 flying hours per mission type is obtained (see Table 5.4.3).

Table 5.4.2. Expected Number of Critical LRU Replacements per Mission

Critical LRU	Mission Type									
	1	2	3	4	5	6	7	8	9	10
1. AMPLIFIER, LEAD AND LAUNCH COMPUTING WUC 74AAB	0.003	0.001	0.010	0.007	0.005	0.015	0.118	0.036	0.009	0.003
2. TURBINE, COOLING WUC 41ABA	0.002	0.001	0.006	0.003	0.002	0.007	0.014	0.010	0.005	0.002
3. TRANSMITTER/RECEIVER WUC 73CAO	0.027	0.042	0.109	0.064	0.042	0.144	0.201	0.179	0.075	0.027
4. SYNCHRONIZER TRANSMITTER WUC 73DFO	0.001	0.002	0.051	0.024	0.005	0.055	0.074	0.066	0.045	0.001
5. MODULATOR, RECEIVER/TRANSMITTER WUC 73BDO	0.007	0.012	0.059	0.033	0.012	0.092	0.128	0.114	0.044	0.007
6. COMPUTER, AIR DATA WUC 52BAA	0.019	0.028	0.077	0.047	0.028	0.106	0.171	0.156	0.066	0.019
7. MACH ASSEMBLY, MAXIMUM SAFE WUC 52BBR	-	-	-	-	-	-	-	-	-	-
8. COMPUTER, FLIGHT CONTROL YAW WUC 52ACA	0.003	0.005	0.017	0.008	0.005	0.024	0.027	0.026	0.013	0.003
9. STABILIZATION PLATFORM UNIT WUC 73AAO	0.034	0.051	0.266	0.201	0.051	0.333	0.439	0.391	0.251	0.034
10. FEEL TRIM ASSEMBLY WUC 52ADA	-	-	-	-	-	-	-	-	-	-
11. NAVIGATIONAL COMPUTER CP812/AJQ-20 WUC 73ABO	0.094	0.120	0.283	0.218	0.143	0.337	0.415	0.352	0.256	0.094

Source: 258 Data System and the Mission Debriefing Form 0-294 for the F-111, Edwards AFB, California.

Table 5.4.3. Expected Number of Critical LRU Replacements per 100 Flying Hours of Each Mission Type

Critical LRU	Mission Time									
	1	2	3	4	5	6	7	8	9	10
1. AMPLIFIER, LEAD AND LAUNCH COMPUTING WUC 74AAB	0.2976	0.513	0.2977	0.2976	0.2970	0.2976	1.1761	0.4803	0.2976	0.2977
2. TURBINE COOLING WUC 41ABA	0.1456	0.0575	0.1674	0.1291	0.1242	0.1397	0.1383	0.1290	0.1525	0.1456
3. TRANSMITTER/RECEIVER SUC 73CAO	2.6713	2.7644	3.1219	2.5706	2.7644	2.8778	2.0096	2.3805	2.4845	2.6713
4. SYNCHRONIZER TRANSMITTER WUC 73DFO	0.0659	0.1487	1.4479	0.9553	0.3007	1.0967	0.7378	0.8800	1.5017	0.1358
5. MODULATOR, RECEIVER/TRANSMITTER WUC 73BDO	0.7356	0.8295	1.6735	1.3149	0.8294	1.8374	1.2827	1.5188	1.4606	0.7356
6. COMPUTER, AIR DATA WUC 52BAA	1.8610	1.8514	2.2010	1.8939	1.8481	2.1113	1.7050	2.0739	2.1892	1.8610
7. MACH ASSEMBLY, MAXIMUM SAFE WUC 52BBR	-	-	-	-	-	-	-	-	-	-
8. COMPUTER, FLIGHT CONTROL YAW WUC 52ACA	0.3285	0.3285	0.4954	0.3285	0.3285	0.4796	0.2727	0.3506	0.4247	0.3285
9. STABILIZATION PLATFORM UNIT WUC 73AAO	3.4122	3.4122	7.6047	8.0507	3.4122	6.6623	4.3860	5.2074	8.3636	3.4122
10. FEEL TRIM ASSEMBLY WUC 52ADA	-	-	-	-	-	-	-	-	-	-
11. NAVIGATIONAL COMPUTER CP 812/AJQ-20 WUC 73ABO	9.4410	7.9760	8.0813	8.7144	9.5442	6.7350	4.1509	5.0934	8.5388	9.3580

Source: 258 Data System and the Mission Debriefing Form 0-294 for the F-111, Edwards AFB, California.

5.5 THE EVALUATION OF CURRENT REPLACEMENT REQUIREMENTS

From the results of Section 5.4, it is not obvious what the procurement policy should be for the Critical LRU's under consideration. The difficulty is due to the fact that in an operational environment the mission mixture is a random variable. If the mission mixture is known or can be estimated then the procurement policy for a particular LRU should be based on

$$K = \sum_{j=1}^{10} p_j K_j \quad , \tag{5.5.1}$$

where the K_j's are the estimated replacements per mission (Table 5.4.2) or the estimated replacements per 100 flying hours for a given mission type (Table 5.4.3) and the p_j's are such that

$$\sum_{j=1}^{10} p_j = 1 \quad . \tag{5.5.2}$$

In this section, the current replacement requirements are evaluated when a random mission mixture is assumed.

Under the random mission mixture assumption, all values between 0 and 1 are possible values of each p_j in (5.5.1). Thus, no matter what mission mixture is selected the corresponding set of p_j's gives rise to a particular value of K in (5.5.1). Here the distribution of K is generated for 500 random mission mixtures. The 50, 85, 90 and 95 percent points of the probability distribution of K for each LRU are given in Table 5.5.1 as well as the current AFLC K-value from Table 5.1.1 Section 5.1. Since the current AFLC K-value from Table 5.1.1 is a particular point on the distribution of K, it follows that the respective percentile points in Table 5.5.1 are indicators of under or over procurement for each Critical LRU. By definition the p^{th} percentile of a probability distribution is that value below which p percent of the distribution of values will fall. For example, the 95^{th} percentile of the distribution of K for Critical LRU - Transmitter/Receiver, WUC 73CAO, is 2.729. This implies that, if the above LRU is procured on the basis of 2.729 replacements per 100 flying

Table 5.5.1. Comparison of K Estimates for Eleven Critical LRU's for Random Mission Mixture

Critical LRU	Current K-Value	$Pr(K \le k) = p^*$			
		0.50	0.85	0.90	0.95
1. AMPLIFIER, LEAD AND LAUNCH COMPUTING WUC 74AAB	0.625	0.378	0.436	0.450	0.470
2. TURBIN, COOLING WUC 41ABA	0.100	0.133	0.138	0.139	0.141
3. TRANSMITTER/RECEIVER WUC 73CAO	0.750	2.633	2.693	2.707	2.729
4. SYNCHRONIZER, TRANSMITTER WUC 73DFO	0.500	0.729	0.830	0.855	0.891
5. MODULATOR, RECEIVER/TRANSMITTER WUC 73BDO	1.333	1.222	1.299	1.319	1.346
6. COMPUTER, AIR DATA WUC 52BAA	1.000	1.961	1.992	1.999	2.010
7. MACH ASSEMBLY, MAXIMUM SAFE WUC 52BBR	0.667	-	-	-	-
8. COMPUTER, FLIGHT CONTROL, YAW WUC 52ACA	0.875	0.367	0.381	0.384	0.389
9. STABILIZATION PLATFORM UNIT WUC 73AAO	2.000	5.402	5.798	5.890	6.036
10. FEEL TRIM ASSEMBLY WUC 52ADA	1.333	-	-	-	-
11. NAVIGATIONAL COMPUTER CP812/AJQ-20 WUC 73ABO	2.000	7.774	8.137	8.226	8.350

Source: 258 Data System and the Mission Debriefing Form 0-294 for the F-111, Edwards AFB, California.

*$Pr(K \le k)$ = Probability that K is less than or equal to the value k is p. For example, the probability that $K \le 1.299$ for critical LRU 5 is equal to 0.85, etc.

hours for a random mission mixture, then there is a 95 percent chance of satisfying the spares requirement for the above LRU. For additional comments, see Appendix V and Section 5.6 below.

5.6 EVALUATION OF THE ANALYSIS

It is important to recognize that as the F-111 Category II Testing continues the data base upon which the above analyses are based will increase, thereby providing additional reliability and maintainability histories for the above LRU's of interest. Since the statistical techniques used here are based on averages, it is well known that as the sample size increases these techniques yield results which converge in probability to the true state of nature provided the inputs are accurate. Moreover, it is also known that these techniques are very robust. Hence, it can be concluded that the above results are reasonably accurate. This conclusion is based on the fact that the inconsistencies found in the data elements of the 258/Mission Debriefing Data System are relatively minor as far as traceable errors are concerned. But it should be recognized that no attempt was made here to validate the total data system or the contents of the data base.

6.0 EXPECTED FOLLOW-ON ACTIVITIES

While the products of Section 5.1 through 5.5 were developed from the current data base, the 258 and debriefing data were not completely debugged to the point where efficient utilization of the system could be accomplished. Hence EAFB currently has urgent need for status reporting of basic data as well as the results of more sophisticated analytical products.

6.1 DEVELOPMENT OF CURRENT MONTHLY PRODUCTS

The anticipated monthly products for EAFB/FTTE are expected to include (but not limited to) some of the following information:

(1) On a monthly and a cumulative basis:

AFSC - WUC - HOURS/FLYING HOUR
AFSC - HOURS/FLYING HOUR
WUC - HOURS/FLYING HOUR

(2) Total maintenance man-hours per flying hour:

(a) Total F-111 system
(b) For each subsystem
(c) For Critical LRU
(d) For important work centers

(3) Aircraft turn-around time

(a) Man-hours
(b) Elapsed hours
(c) Active hours

(4) Aircraft Status Report

The objective for this type of reporting will be to demonstrate the capability of the operational reporting system to provide timely, automated data products to management. Consequently, the spectrum of the type of products produced will not be limited to those indicated above, but will include the results of analysis to any degree of sophistication required to provide products which can be used simply and effectively by management to enhance their operational performance.

6.2 ANALYTICAL MODELLING

As indicated in Section 6.1, the purpose of all analytical modelling in the follow-on activities will be to provide products which can be used simply and effectively by management to enhance their operational performance. When viewed in this light the products of Section 5.1 through 5.5 enable more effective decisions in the areas of maintenance and replacements. The objective of follow-on modelling will be to continue this type of analysis in areas of benefit to SAMSO/AFFTC.

Analytical techniques will be provided for estimating any elements which are indicated as necessary to the effective support of the system. Problems which AFLC have in providing adequate support will be approached and recommendations made, subject to concurrance of SAMSO and AFFTC.

7.0 CONCLUSION

From this study the following observations are made:

(1) The storage and retrieval of a large volume of operating and maintenance data on a timely basis appears feasible.

This program has demonstrated that accuracy of reporting operational requirements is easier for a larger volume of data and for more diverse requirements when the operating data is available for automated processing using analytical models developed for this purpose.

(2) Category II operating data can be used to provide relatively accurate estimates of system operating parameters and/or requirements.

The identification of the probability distribution of maintenance events for any given level of hardware for all activity on the total system which relates to that level of the system, provides an analytical tool for more accurate forecasting of operational performance in the actual deployment environment. In addition, the development of risk levels for replacements per hundred hours of flying time enables strong justification for LRU procurement levels.

(3) The usefulness of the 258/debriefing data file to the improvement of some estimates of reliability/maintainability parameters has been demonstrated.

The ability to define an accurate time-between-failure and time-to-maintain has been adequately demonstrated. In addition, automatic plotting of results has been shown a valuable adjunct to the clarification of results.

(4) The formatted file system will provide a useful means for access to system operating data when properly installed.

In addition to rapid retrieval of stored data, FFS provides an efficient means to relate events simultaneously in several different dimensions. This provides for example, the correlation among part numbers, work unit codes, and serial numbers.

APPENDIX I

IBM FORMATTED FILE SYSTEM (FFS) ADAPTATION REQUIREMENTS

The IBM Formatted File System was written for the IBM 7094 Model II Computer in Macro Assembly Program (MAP) Language and as such its adaptation is restricted to the IBM 7094 or to comparable computing equipment with an IBM 7094 emulation capability. The current hardware requirements for FFS is an IBM 7094 Computer with

(1) 32K Core, and

(2) 17 tape drives or their equivalent with a combination of a 1301 disk file and tapes.

However, due to modifications to the system it has been adapted to the IBM 7044/7094 DCS Computer as well as the IBM 7090 Computer. Here it should be recognized that the above core and Input/Output requirements must be satisfied. Likewise FFS has also been adapted to the IBM 360 by means of the IBM 360/7094 emulator.

This study has shown that FFS is a very useful tool as far as storage, retrieval and data base management from which reliability and maintainability analysis can be made. Thus it seems that a useful next step in the development of FFS is to rewrite the entire system in a high level language such as FORTRAN IV or COBOL so that it may be adapted to a variety of computering hardware without major modifications.

APPENDIX II

PART I

THE DISTRIBUTION OF MAINTENANCE EVENTS FOR EACH CRITICAL LRU

0.0 SUMMARY

In Section 5.2 the results of fitting maintenance data to three well known probability distributions were summarized. Here additional details are given in order to make this report self contained. Part I of this appendix deals with probability and statistical questions concerning fitting sample data to theoretical distribution functions and gives the detailed results of problem (1) mentioned in Section 5.0. Part II of this appendix gives the algorithm for obtaining the sample data and the description and flow chart of the computer program used.

1.0 INTRODUCTION

In SAMSO Report No. 67-12, it was shown that man-hours-to-repair the actual hardware as well as time to failure or time between failure for subsystems of the F-111 Category II Test Data can be fitted to certain standard probability distributions automatically. Here the distribution of the total time associated with maintenance events for certain items of interest from the F-111 Category II Test Data is considered. In order to fix ideas the following definition is given.

Definition 1.0: The administrative and technical activities associated with the restoration of a device, etc., to its operating state is said to be a maintenance event.

Obviously, a maintenance event may consist of a series of activities such as repair, test, or preventive maintenance, etc. With reference to the F-111, the difference between line and shop maintenance are distinquished. In general, line maintenance is carried out on devices, etc., on the aircraft while shop maintenance is carried out on such devices, etc., which have been removed from the aircraft. Thus, from line and shop maintenance events the sample distribution function of elapsed, active, and man hours respectively, can be derived which will allow inference to be made concerning the effectiveness of a given maintenance

policy. Here, however, the discussion is limited to the distribution of time associated with line maintenance events.

With reference to Definition 1.0 let T be the time required to restore a particular device, etc., to its operating state. When T includes troubleshooting time, delay time due to shortages of parts, transportation or other nonrelated factors, as well as, the actual time to restore the device, etc., to its operating state, then T is the elapsed time associated with the maintenance event under consideration. On the other hand, when T includes only the actual time to restore the device, etc., to its operating state, then T is the active time associated with the maintenance event under consideration. Here T will always be measured in hours. Hence, without loss of generality, T is the elapsed hours or the active hours for a particular maintenance event. Finally, if T is the time required for maintenance personnel to restore the device, etc., to its operating state then obviously T is the man-hours for the particular maintenance event.

Observe that when a device, etc., malfunctions or fails which gives rise to a maintenance event the respective elapsed, active and man hours for the event cannot be predicted until the maintenance activity on the device, etc., under consideration has been completed. Thus from a statistical point of view, T is a random variable. By definition a random variable is a rule (function) which assigns to each maintenance event a corresponding number t (time). To fix ideas, consider a population of identical devices, etc., which have failed or malfunctioned and let f(t) dt represent the proportions of the population of devices, etc., which can be restored to their operating state in time dt. Then by definition

$$F(t) = \Pr\left[T \le t\right] = \int_0^t f(x)\,dx \qquad (1.1)$$

is the distribution function of the random variable T. From a statistical point of view any function F with the following properties is said to be a distribution function

(i) $F(-\infty) = 0$,

(ii) $F(t)$ is non-decreasing for $-\infty < t < \infty$,

(iii) $F(\infty) = 1$.

In the continuous case a random variable T may be defined in terms of its density function. Hence, any function f with the properties

$$\text{(i)} \quad f(t) \geq 0, \quad -\infty < x < \infty$$

$$\text{(ii)} \quad \int_{-\infty}^{\infty} f(t)\, dt = 1$$

can serve as a density function of the continuous random variable T and (1. 1) gives the distribution function of T since $t \geq 0$.

If T denotes elapsed hours for the collection of maintenance events generated by the above population of devices, etc., then F(t) is the distribution function for elapsed hours for that population of devices, etc. Here F(t) may be interpreted as being the chance of restoring any device, etc., from the population to its operating state in t elapsed hours, etc.

Unfortunately, the total population of devices, etc., of interest, cannot be observed, instead, only random observations on a particular device, etc., can be made when it fails or malfunctions. This is equivalent to random sampling from the population of such devices, etc., which implies that a value of T is selected at random from F(t), since the probability distribution of T for the particular device, etc., observed has the same probability distribution as the population. Thus, if the maintenance events are observed for a particular device, etc., over a period of time, a sample of values of T will be observed namely, t_1, t_2, $t_3, \ldots, t_n$. Suppose the t_j's are ordered. In general, let $t_{(1)}, t_{(2)}, \ldots, t_{(n)}$ denote the ordered t_j's, then by definition

$$S_n(t) = \begin{cases} 0: & \text{If } t < t_{(1)} \\ k/n: & \text{If } t_{(k)} \leq t < t_{(k+1)}; k = 1, 2, \ldots, n-1 \\ 1: & \text{If } t > t_{(n)} \end{cases} \qquad (1.2)$$

is the sample distribution function. In (1. 2) k denotes the number of $t_{(j)}$'s within the range $(t_{(1)}, t_{(k)})$. Here $S_n(t)$ is the observed frequency in n maintenance events, for which $T \leq t$, whose true probability is F(t), the distribution function of the random variable T. It is also apparent that $S_n(t)$ is a random variable since it is based on a sample of the times

associated with maintenance events. The importance of $S_n(t)$ is that for large samples (as the sample size n becomes infinite), $S_n(t)$ converges in probability to F(t) for any fixed t. Due to this fact, it is meaningful to seek the theoretical distribution function F(t) that $S_n(t)$ approximates when the true probability distribution of T is not known. In this report only the following probability distributions are considered.

Definition 1.1 (Log-normal): If the random variable T is such that $T' = \log_e(T)$ has the density

$$f(t'|\mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp \left\{ \frac{1}{2}\left(\frac{t'-\mu}{\sigma}\right)\right\}^2 . \tag{1.3}$$

$-\infty < t' < \infty$, where μ and σ^2 denote the mean and variance of T', then T is said to be log-normal with mean

$$m = E(T) = \exp(\mu + \sigma^2/2) , \tag{1.4}$$

and variance

$$VAR(T) = \exp\left\{2(\mu + \sigma^2)\right\} - \exp\left\{2\mu + \sigma^2\right\} . \tag{1.5}$$

Definition 1.2 (Exponential): A random variable T is said to be distributed as an exponential distribution with parameter λ if its density is

$$f(t|\lambda) = \lambda \exp(-\lambda t) . \tag{1.6}$$

Definition 1.3 (Weibull): A random variable T is said to be distributed as a Weibull distribution with parameters β and λ^* if its density is

$$f(t|\beta, \lambda^*) = \beta \lambda^* t^{\beta-1} \exp(-\lambda^* t^\beta) . \tag{1.7}$$

In SAMSO Report No. 67-12, it was shown that a particular distribution function $F(t)$ can be compared with $S_n(t)$ by means of the Kolmogorov-Smirnov statistic. Generally, suppose $F(t)$ is a particular distribution function we wish to compare with $S_n(t)$. Since $F(t)$ is known, it would be possible to calculate the value of $|S_n(t) - F(t)|$ for any desired value of t. Furthermore, it is reasonably clear that it would be possible to calculate the value of the quantity

$$D_n = \sup_t | S_n(t) - F(t)| \tag{1.8}$$

which is the maximum vertical distance between the graphs of $F(t)$ and $S_n(t)$ over the range of possible t values (see Figure 5.2.1 of Section 5.2). Observe that D_n is a random variable with a given distribution function. According to Fisz [3], the random variable $D_n\sqrt{n}$ is distributed as $Q_n(D_n\sqrt{n})$ which is approximately

$$Q(\lambda) = \begin{cases} \sum_{k=-\infty}^{n} (-1)^k \exp\left(-2k^2\lambda^2\right) \text{ for } \lambda > 0 \\ 0 \text{ for } \lambda \leq 0 \end{cases} \tag{1.9}$$

for large n, where

$$Q_n(\lambda) = \begin{cases} \Pr(D_n\sqrt{n}<\lambda) = \Pr\left(D<\frac{\lambda}{\sqrt{n}}\right) \text{ for } \lambda > 0 \\ 0 \text{ for } \lambda \leq 0. \end{cases} \tag{1.10}$$

Since $Q(\lambda)$ does not depend on $F(t)$ we can use D_n to test hypotheses and construct confidence limits concerning the particular distribution function $S_n(t)$ approximates.

As mentioned above, the random variable D_n is known as the Kolmogorov-Smirnov statistic and the procedure of comparing $S_n(t)$ with $F(t)$ by means of D_n is known as the Kolmogorov-Smirnov goodness of fit test. The procedure is the following: Suppose we wish to test the hypothesis

$$H_0: S_n(t) \equiv F(t)$$

using the statistic D_n. If H_0 is true we would expect D_n to be small and if H_0 is false we would expect D_n to be large. Since (1.10) gives the probability that the statistic D_n is less than $\lambda/\sqrt{n}$, it follows that

$$\Pr(D_n \geq \lambda/\sqrt{n}) = 1 - Q(\lambda). \tag{1.11}$$

Hence if D_n is large the right hand side of (1.11) will be small. In statistical terms small values of $1 - Q(\lambda)$ create doubt as to whether the theoretical distribution of the random variable T has the form F(t). Thus the above procedure can be used for testing the hypothesis $H_0: S_n(t) \equiv F(t)$ against $H_1: S_n(t) \not\equiv F(t)$ which rejects H_0 when D_n is too large. This is accomplished by choosing a level of significance $\alpha = 0.01$, 0.05, or 0.025, etc., and determining $D_{n,\alpha}$ for which

$$1 - Q\left(D_{n,\alpha}\sqrt{n}\right) \leq \alpha. \tag{1.12}$$

Then D_n is calculated using (1.8). If $D_n \geq D_{n,\alpha}$ reject H_0.

APPENDIX II
PART I

2.0 THE PROCEDURE FOR FITTING MAINTENANCE DATA FOR CRITICAL LRU'S ON THE F-111

For each Critical LRU the following hypotheses are considered:

1) Log-normal whose logarithm is normal (0, 1)

$$H_{0,0}: S_n(t') \equiv F(t'|0, 1) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t'} \exp\left(-\frac{1}{2}z^2\right)dz$$

where $t' = \log_e(t)$,

2) Log-normal whose logarithm is normal (μ, σ^2)

$$H_{0,1}: S_n(t') \equiv F(t'|\mu, \sigma^2) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t'} \exp\left\{-\frac{1}{2}\left(\frac{z-\mu}{\sigma}\right)^2\right\}dz,$$

3) Exponential with parameter λ

$$H_{0,2}: S_n(t) \equiv F(t|\lambda) = 1 - \exp(-\lambda t),$$

and finally

4) Weibull with parameters β and λ^*

$$H_{0,3}: S_n(t) \equiv F(t|\beta, \lambda^*) = \beta\lambda^* \int_0^t z^{\beta-1} \exp(-\lambda^* z^\beta)dz.$$

Observe that the parameters μ, σ, λ, β and λ^* are unknown for the above LRU's of the F-111. Hence, they must be estimated from the data. It is well known that

$$\bar{t} = \frac{1}{n}\sum_{j=1}^{n} t_j,$$

$$s_t^2 = \frac{1}{n-1}\sum_{j=1}^{n} (t_j-\bar{t})^2 \qquad (2.1)$$

are unbiased estimators of μ and σ^2 for a normal distribution. Similarly,

$$\hat{\lambda} = (n-1)/\sum_{j=1}^{n} t_j \tag{2.2}$$

is an unbiased estimator of λ for an exponential distribution. Unfortunately, the parameters β and λ^* of the Weibull distribution cannot be determined in a straight forward manner. Here the method of moments is used to estimate β and λ^*. It can be shown that the mean and variance of the Weibull distribution are given by

$$E(T) = \Gamma\left(1 + \frac{1}{\beta}\right)\lambda^{*^{-\frac{1}{\beta}}}$$

$$VAR(T) = \left\{\Gamma\left(1 + \frac{2}{\beta}\right) - \left(\Gamma\left(1 + \frac{2}{\beta}\right)\right)^2\right\} \lambda^{*^{-\frac{2}{\beta}}}, \tag{2.3}$$

where $\Gamma(\ .\ )$ is the gamma function. Equating these expressions to the mean and variance of the sample data it follows that

$$\Gamma\left(1 + \frac{1}{\beta}\right)\lambda^{*^{-\frac{1}{\beta}}} = \frac{1}{n}\sum_{j=1}^{n} t_j = \bar{t}$$

$$\left\{\Gamma\left(1 + \frac{2}{\beta}\right) - \left(\Gamma\left(1 + \frac{1}{\beta}\right)\right)^2\right\}\lambda^{*^{-\frac{2}{\beta}}} = \frac{1}{n-1}\sum_{j=1}^{n} (t_j - \bar{t})^2 = s^2. \tag{2.4}$$

Solving the first equation in (2.4) for

$$\lambda^{*^{-\frac{1}{\beta}}} = \frac{\bar{t}}{\Gamma\left(1 + \frac{1}{\beta}\right)} \tag{2.5}$$

and substituting in the second and solving for the ratio of gamma functions, it follows that

$$\frac{\Gamma\left(1 + \frac{2}{\beta}\right)}{\Gamma\left(1 + \frac{1}{\beta}\right)^2} = 1 + \left(\frac{s}{\bar{t}}\right)^2. \tag{2.6}$$

Since β is the only unknown parameter in (2.6) it can be determined so that equality holds, then λ^* can be determined by (2.5). The values $\hat{\beta}$ and $\hat{\lambda}^*$ determined by (2.6) and (2.5) are the required estimates of β and λ^* for the Weibull distribution.

In order to carry out the goodness of fit test for the above hypotheses, the parameters in the respective distribution functions are replaced by their estimates above and use (1.8). A computer program for testing the above goodness of fit hypotheses is described in DuBois [2]. Here that program is used to carry out the analysis automatically on the computer.

APPENDIX II

PART I

3.0 THE MOST LIKELY DISTRIBUTION OF MAINTENANCE EVENTS FOR CRITICAL LRU'S ON THE F-111

It should be recognized that it is difficult to distinguish among various non-symmetrical probability distributions on the basis of actual observations, since there is only significant difference in the tails of such distributions. But in many applications actual observations are sparsed from the tails of such distributions due to limited sample sizes. In this study, there exist the unusual opportunity of having an increasing data base due to the continuation of the Category II testing of the F-111. Thus, as the data base increases the sample sizes for maintenance events for the Critical LRU's studied here also increases and, hence, $S_n(t)$ for these LRU's converge in probability to their respective $F(t)$. Since the procedure for fitting $S_n(t)$ to $F(t)$ is completely automated, the fitting procedure can be carried out each time the data base is updated and the change in shape of $S_n(t)$ can be observed, if any. Obviously, inference can be made concerning the effectiveness of a given maintenance policy under evaluation based on the updated $S_n(t)$ for the critical LRU's under consideration. The results for four of the eleven Critical LRU's studied in this report are given. Seven of the Critical LRU's considered had insufficient data and, hence, the above analysis is not applicable.

The results are summarized in Tables 1 through 10. The tables are grouped by Critical LRU for shop and line maintenance events. For example, Tables 1 and 2 give the results for shop and line maintenance hours respectively, for Critical LRU-Transmitter/Receiver, WUC 73CAO. The plots of the sample distribution functions and the respective theoretical distributions for maintenance hours follow each table. For example, the distribution plots for shop maintenance hours for the above LRU are given in Figures 1 through 9 following Table 1 and the corresponding plots for line maintenance hours are given in Figures 10 through 18 following Table 2. The remaining tables and plots are organized in a similar manner.

The symbolic notations used in the tables are defined as follows:

(1) $L(N(\overline{t'}, s^2_{t'}))$ denotes the hypothesis that T is distributed as a log-normal distribution whose logarithm is normally distributed with mean $\overline{t'}$ and variance $s^2_{t'}$ where $t' = \log_e(t)$.

(2) $E(\hat{\lambda})$ denotes the hypothesis that T is distributed as an exponential distribution with parameter $\hat{\lambda}$.

(3) $W(\hat{\beta}, \hat{\lambda}^*)$ denotes the hypothesis that T is distributed as a Weibull distribution with parameters $\hat{\beta}$ and $\hat{\lambda}^*$.

Each hypothesis is tested at the 0.5 level of significance. However, $1 - Q(D_n\sqrt{n})$ in the tables is the computed percentage point of $Pr(D_n \geq \lambda/\sqrt{n})$, hence, the reader may wish to use some other level of significance.

It should be recognized that one cannot conclude that $H_{0,j}$ is not true if $1 - Q(D_n\sqrt{n})$ is very small. Although the probability of the event $D_n \geq \lambda/\sqrt{n}$ is very small, provided $H_{0,j}$ is true, such an event may occur in practice. At this point the statistician makes a decision; he chooses a critical probability $\alpha = 0.05$, or 0.01, etc. (level of significance) such that if under $H_{0,j}$ the probability of an outcome more extreme than the observed event is not greater than α, he will reject $H_{0,j}$. On the other hand, if the probability f the observed event or worse is greater than α, unfortunately, it can only be said that the data does not contradict $H_{0,j}$. However, the notion of accepting $H_{0,j}$ is well defined in statistical theory, but this requires a discussion of the concepts of the power of a statistical test and confidence intervals. Therefore, the analysis is restricted to rejecting $H_{0,j}$ when $\alpha = 0.05$.

From Table 1 observe that $1 - Q(D_n\sqrt{n})$ for $H_{0,0}$ and $H_{0,2}$ is essentially 0 which creates serious doubt as to whether shop elapsed hours for Critical LRU Transmitter/Receiver, WUC 73CAO, are distributed as a log-normal distribution whose logarithm is normally distributed with mean 0 and variance 1 or distributed as an exponential distribution with parameter $\hat{\lambda} = 0.0143$. For $n = 18$ and $\alpha = 0.05$, it is found from Fisz [3] that $D_{18,\alpha} = 0.3205$. However, $1 - Q(D_n\sqrt{n})$ may be compared with α directly. Since $D_{18}(N(0, 1)) > D_{18,\alpha}$ and $D_{18}(0.0143) > D_{18,\alpha}$, $H_{0,0}$ and $H_{0,2}$ are rejected. If log-elapsed hours are assumed to be distributed as a normal distribution with mean 2.11 and

variance 4.28 then $D_{18}(N(2.11, 4.28)) < D_{18,\alpha}$. Thus the test does not lead to rejection of $H_{0,1}$. Similarly, the test does not lead to rejection of $H_{0,3}$. Finally, since $1 - Q(D_n\sqrt{n})$ for the Weibull distribution is less than $1 - Q(D_n\sqrt{n})$ for the normal distribution N(2.11, 4.28), it follows that shop elapsed hours for Critical LRU - Transmitter/Receiver, WUC 73CAO, are more likely to be distributed as a log-normal distribution whose logarithm is normally distributed with mean $\overline{t'} = 2.11$ and variance $s_{t'}^2 = 4.28$. The corresponding plots are given in Figures 4, 5 and 6. Finally, the remaining results are interpreted in a similar manner.

Table 1: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}: S_n(t) \equiv F(t\|\theta)$	Sample Size	$\bar{t}$	s_t	Graph	D_n	$1 - Q(D_n\sqrt{n})$	Decision
Transmitter/Receiver	L(N(0, 1))	18	-	-	1	0.6019	0.0000	Reject
WUC 73CA0	L(N(1.40, 1.17))	18	-	-	1	0.2267	0.3130	
	E(0.0995)	18	9.49	17.57	2	0.3421	0.0296	Reject
Shop Active Hours	W(0.5760, 0.3574)	18	9.49	17.57	3	0.3076	0.0662	
	L(N(0, 1))	18	-	-	4	0.6019	0.0000	Reject
Shop Elapsed Hours	L(N(2.11, 4.28))	18	-	-	4	0.2523	0.2010	
	E(0.0143)	18	65.82	142.30	5	0.5766	0.0000	Reject
	W(0.512[illegible], 0.1635)	18	65.82	142.30	6	0.3178	0.0528	
	L(N(0, 1))	18	-	-	7	0.6973	0.0000	Reject
Shop Man Hours	L(N(1.89, 1.33))	18	-	-	7	0.1673	0.6948	
	E(0.0721)	18	13.10	19.07	8	0.2495	0.2125	
	W(0.7020, 0.1935)	18	13.10	19.07	9	0.1759	0.6331	

Source: 258 Data System for the F-111, Edwards AFB, California.

$L(N(\mu, \sigma^2))$ = Log-normal distribution whose logarithm is normally distributed with mean μ and variance σ^2.

$E(\lambda)$ = Exponential with parameter λ.

$W(\beta, \lambda)$ = Weibull with parameters β and λ.

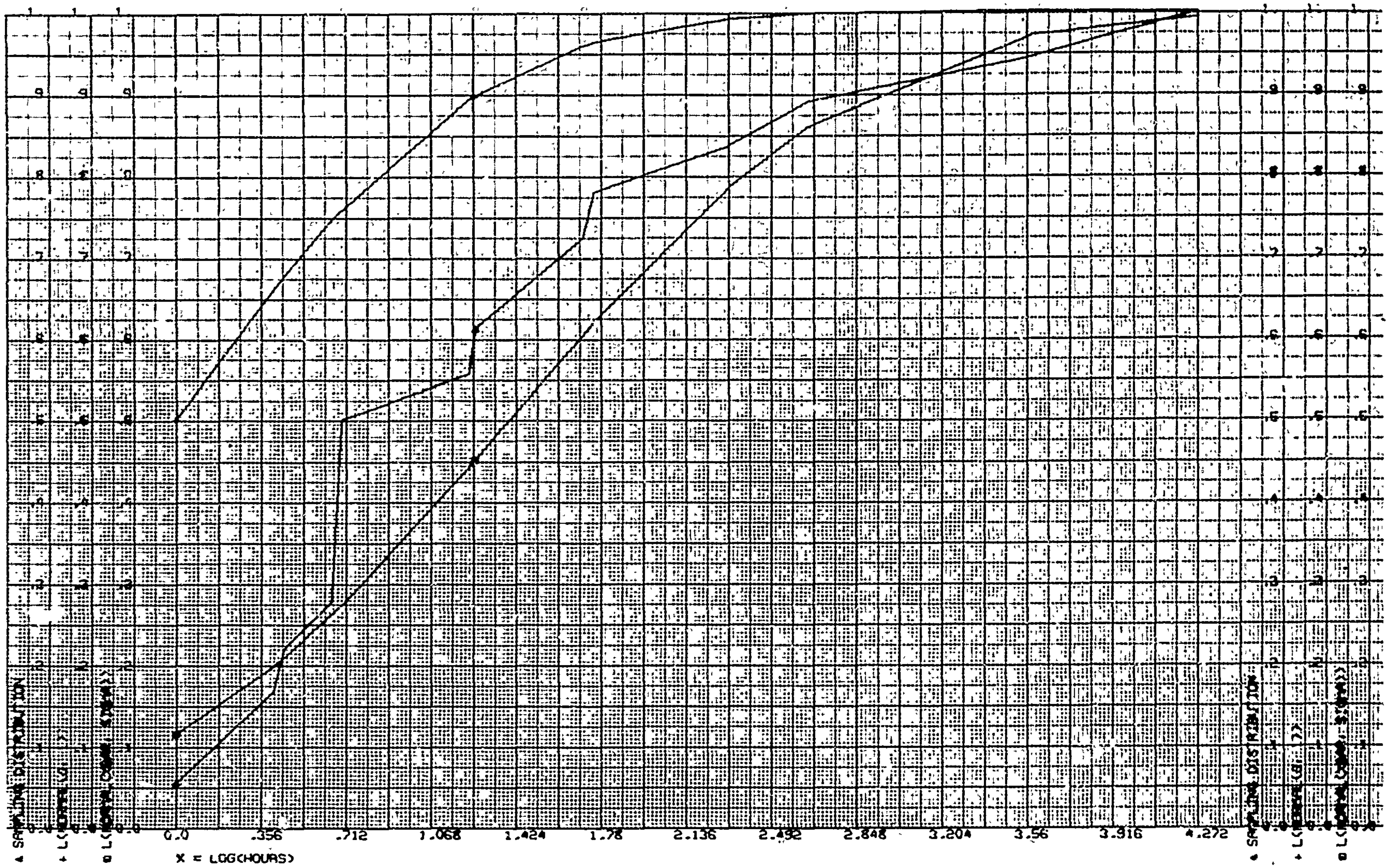

Figure 1. Test for Log Normality: Critical LRU - Transmitter/Receiver, Shop Active Hours WUC 73CAO

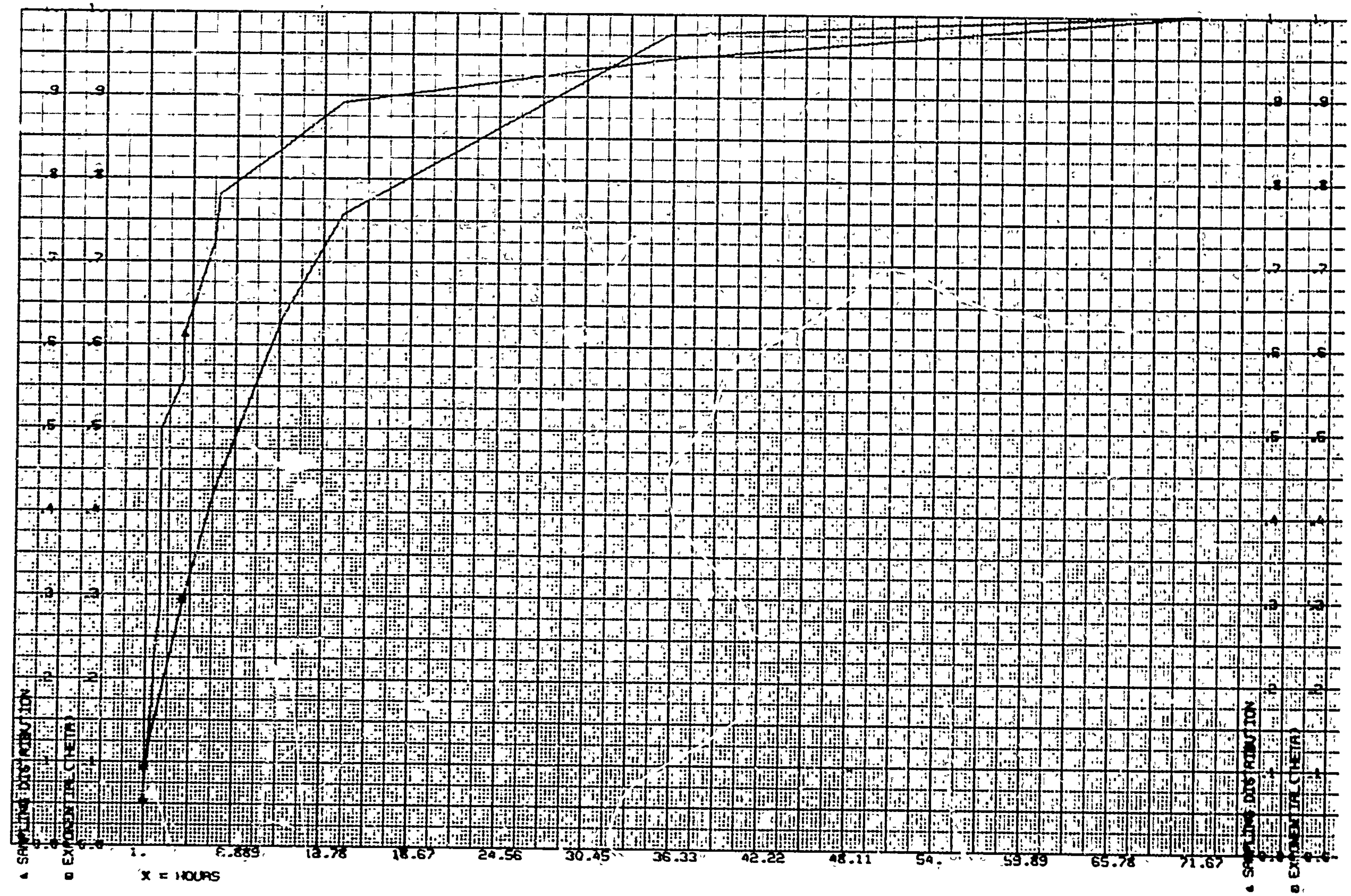

Figure 2. Test for Exponential Data: Critical LRU - Transmitter/Receiver, Shop Active Hours WUC 73CAO

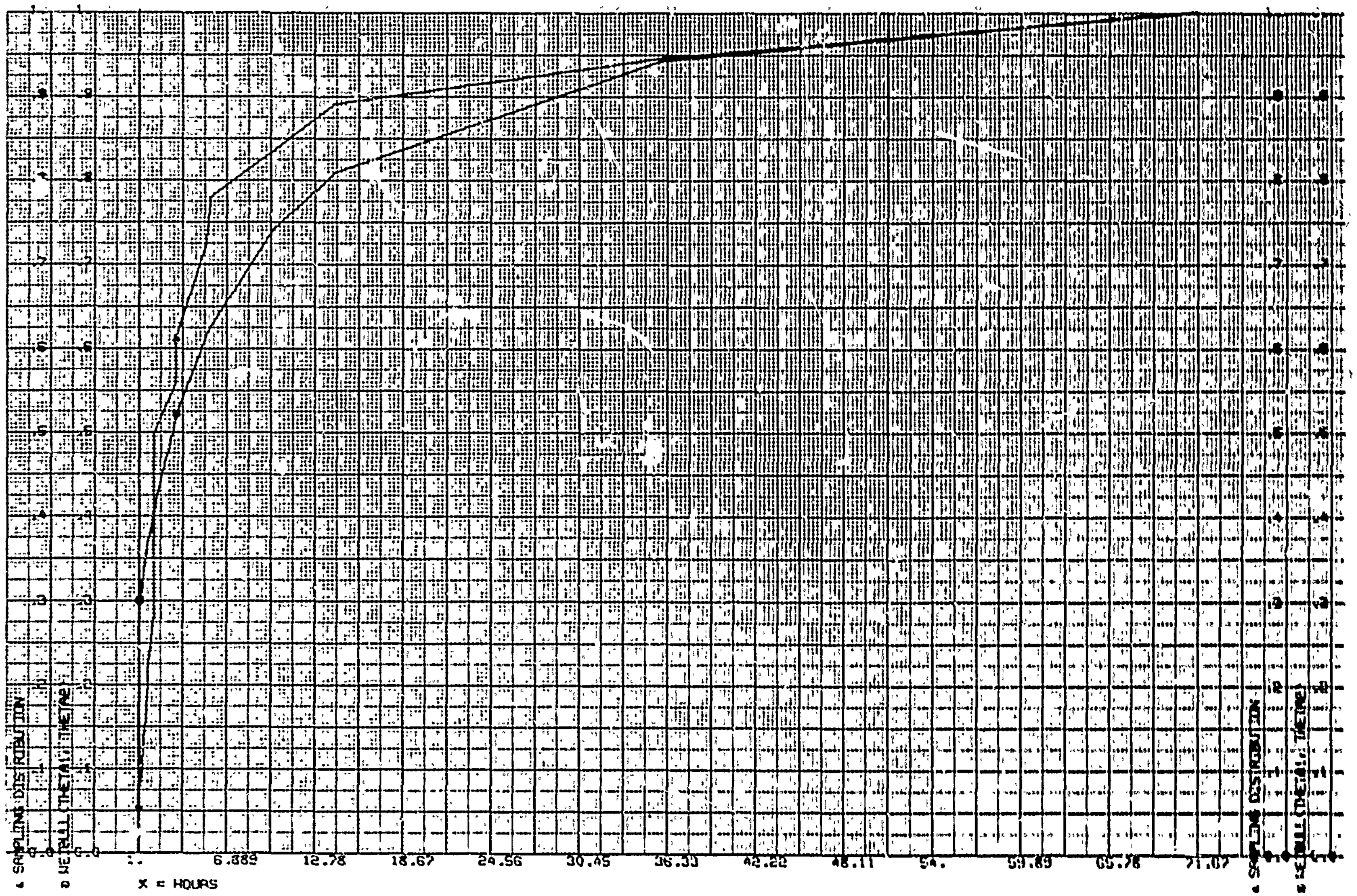

Figure 3. Test for Weibull Data: Critical LRU - Transmitter/Receiver, Shop Active Hours WUC 73CAO

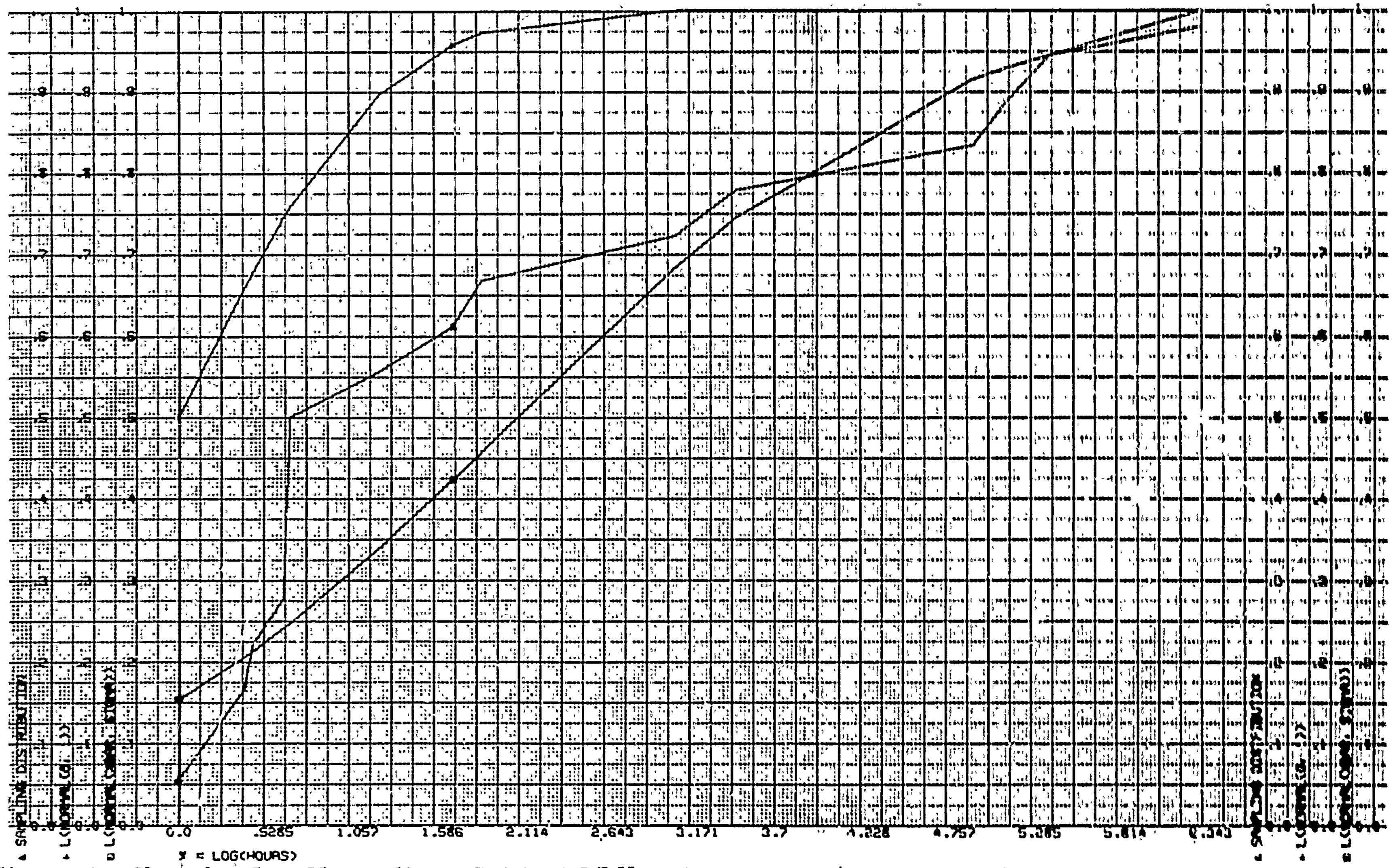

Figure 4. Test for Log Normality: Critical LRU - Transmitter/Receiver, Shop Elapsed Hours WUC 73CAO

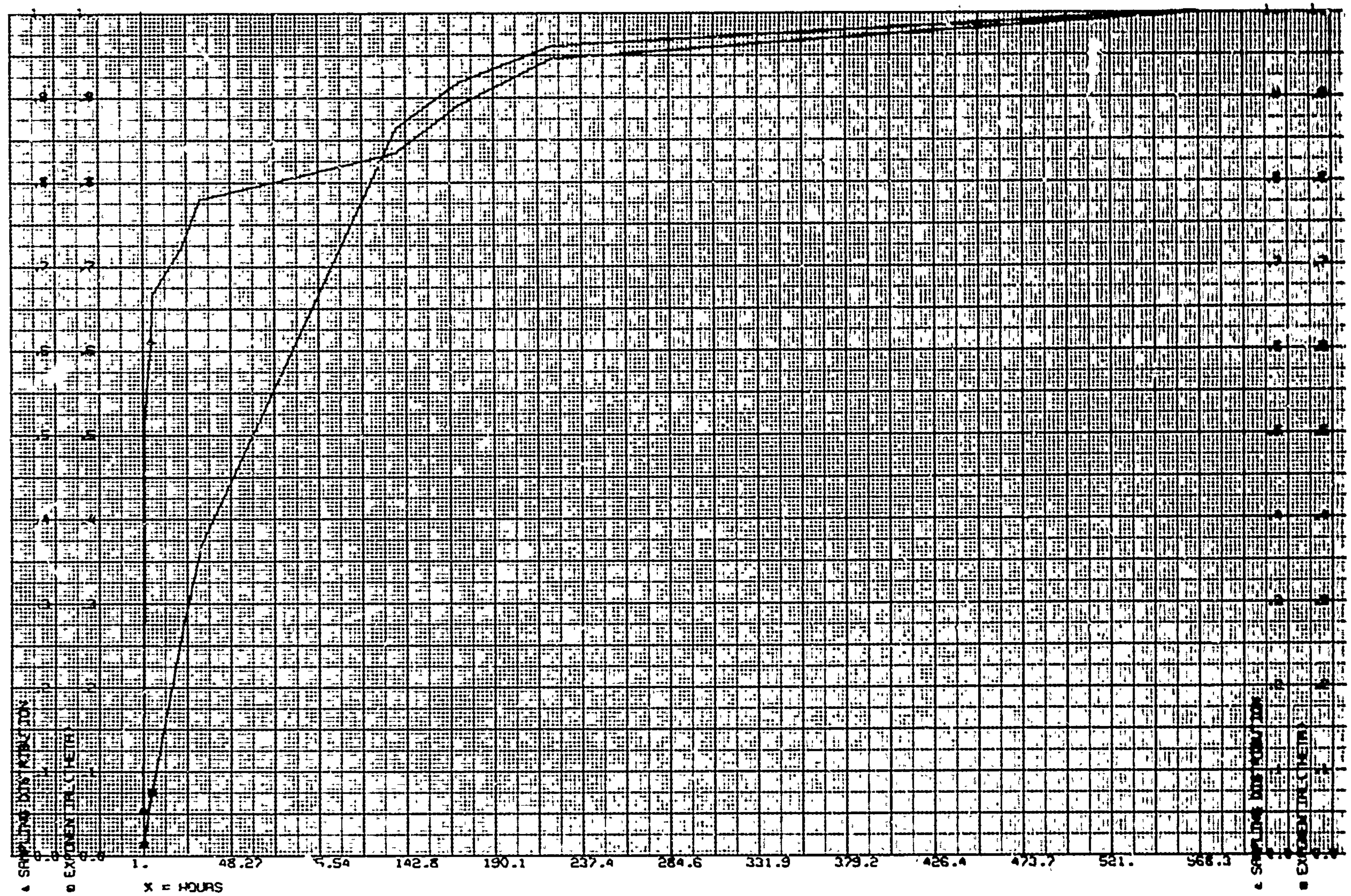

Figure 5. Test for Exponential Data: Critical LRU - Transmitter/Receiver, Shop Elapsed Hours WUC 73CAO

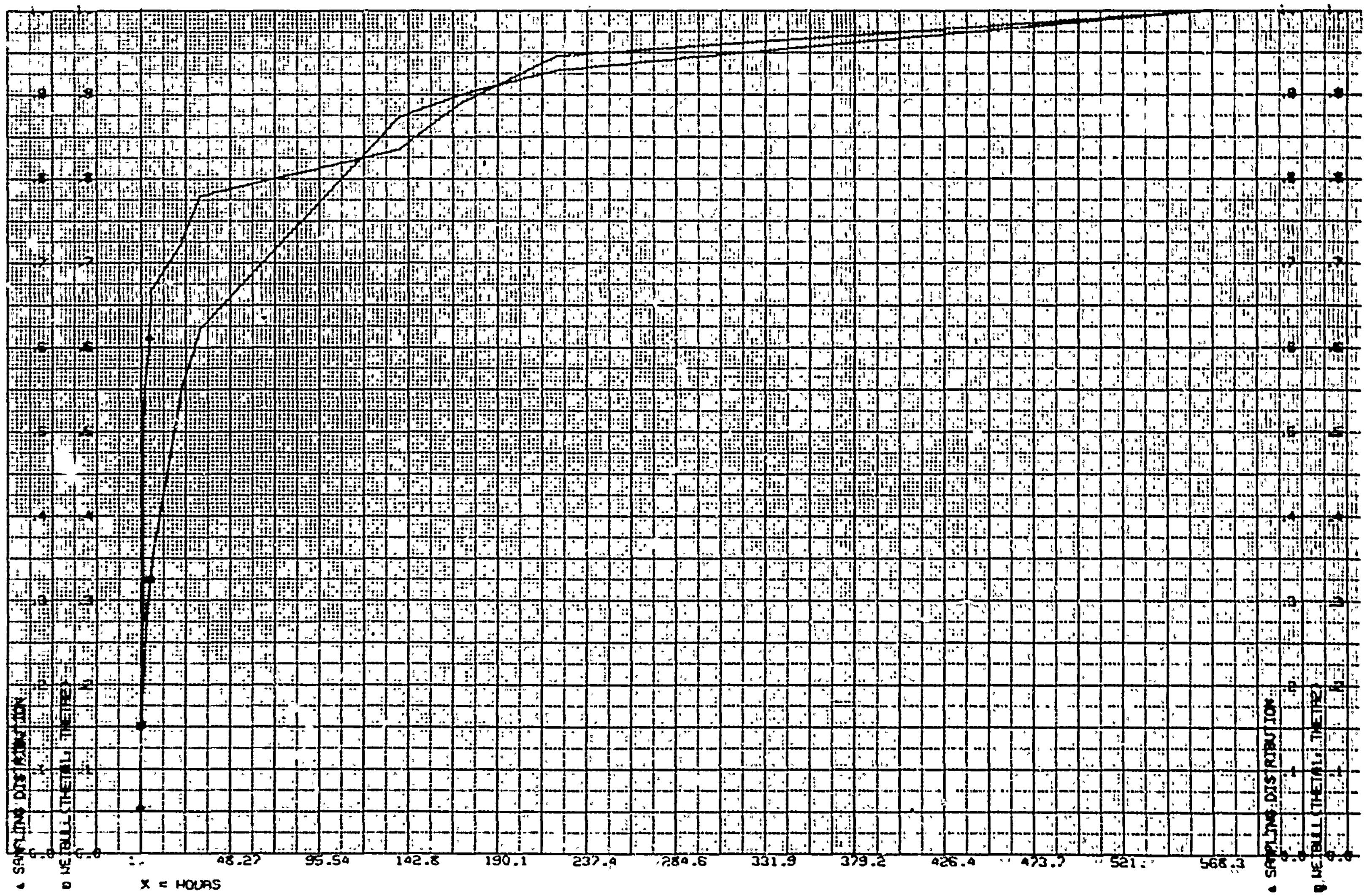

Figure 6. Test for Weibull Data: Critical LRU - Transmitter/Receiver, Shop Elapsed Hours WUC 73CAO

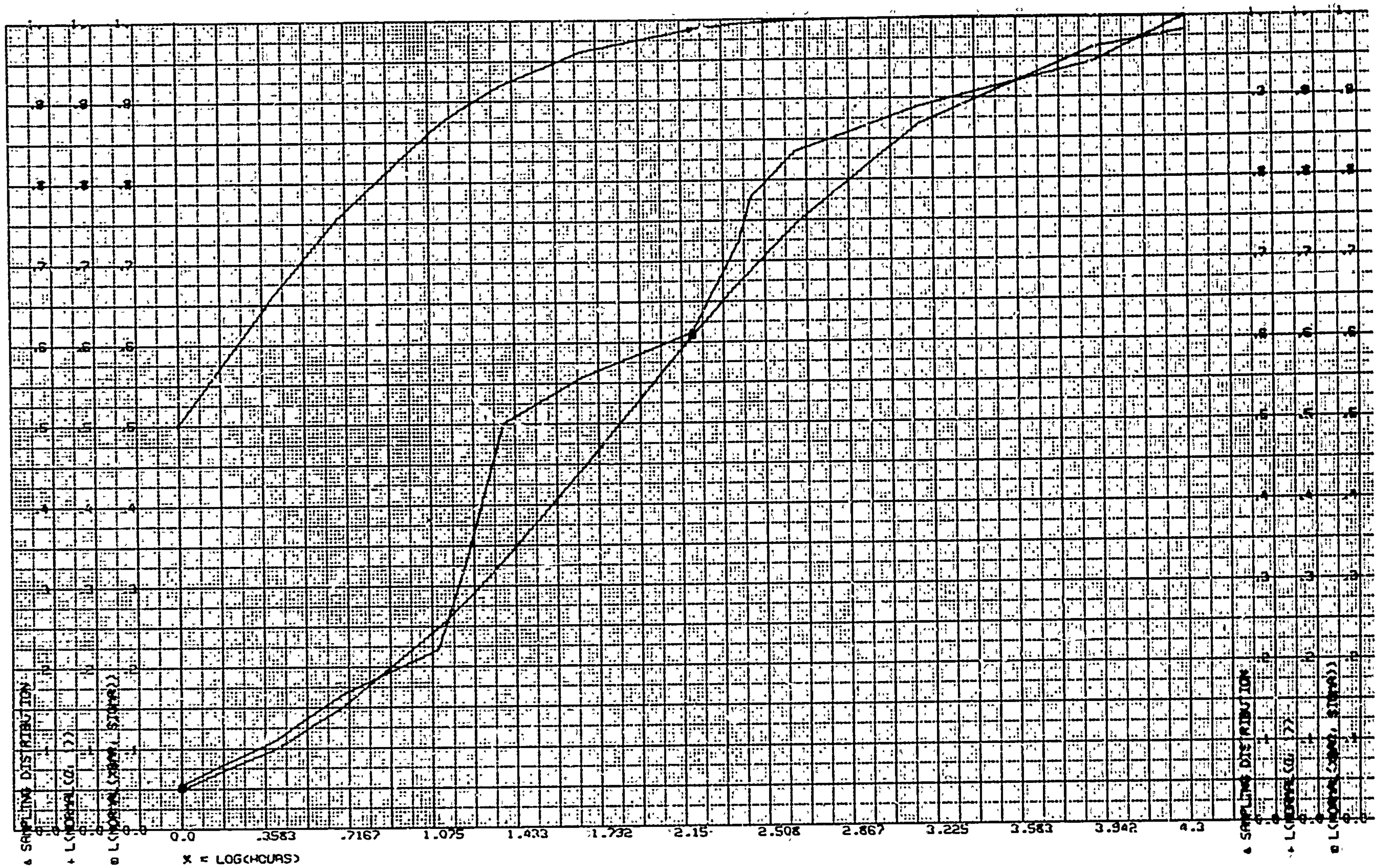

Figure 7. Test for Log Normality: Critical LRU - Transmitter/Receiver, Shop Man Hours WUC 73CAO

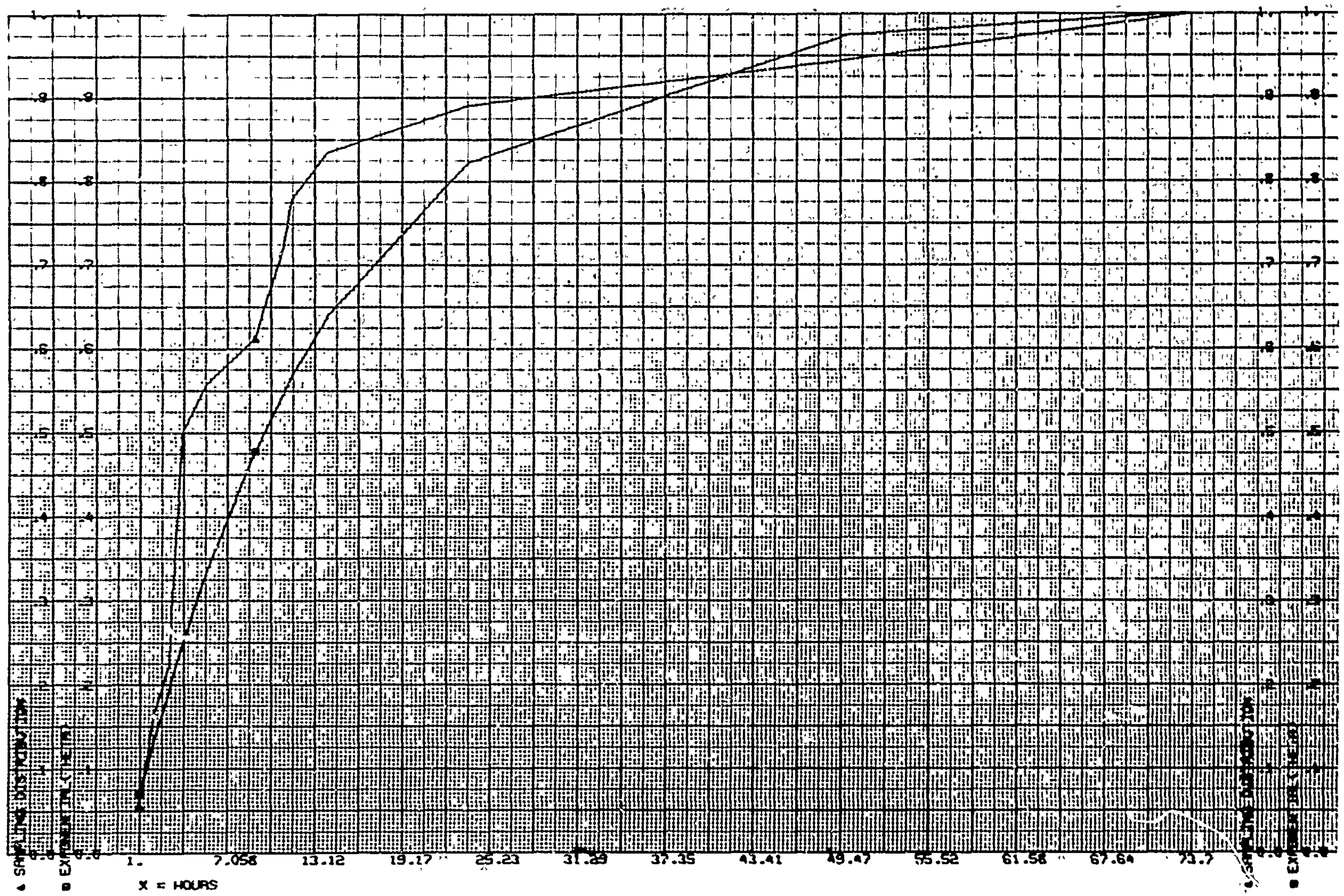

Figure 8. Test for Exponential Data: Critical LRU - Transmitter/Receiver, Shop Man Hours WUC 73CAO

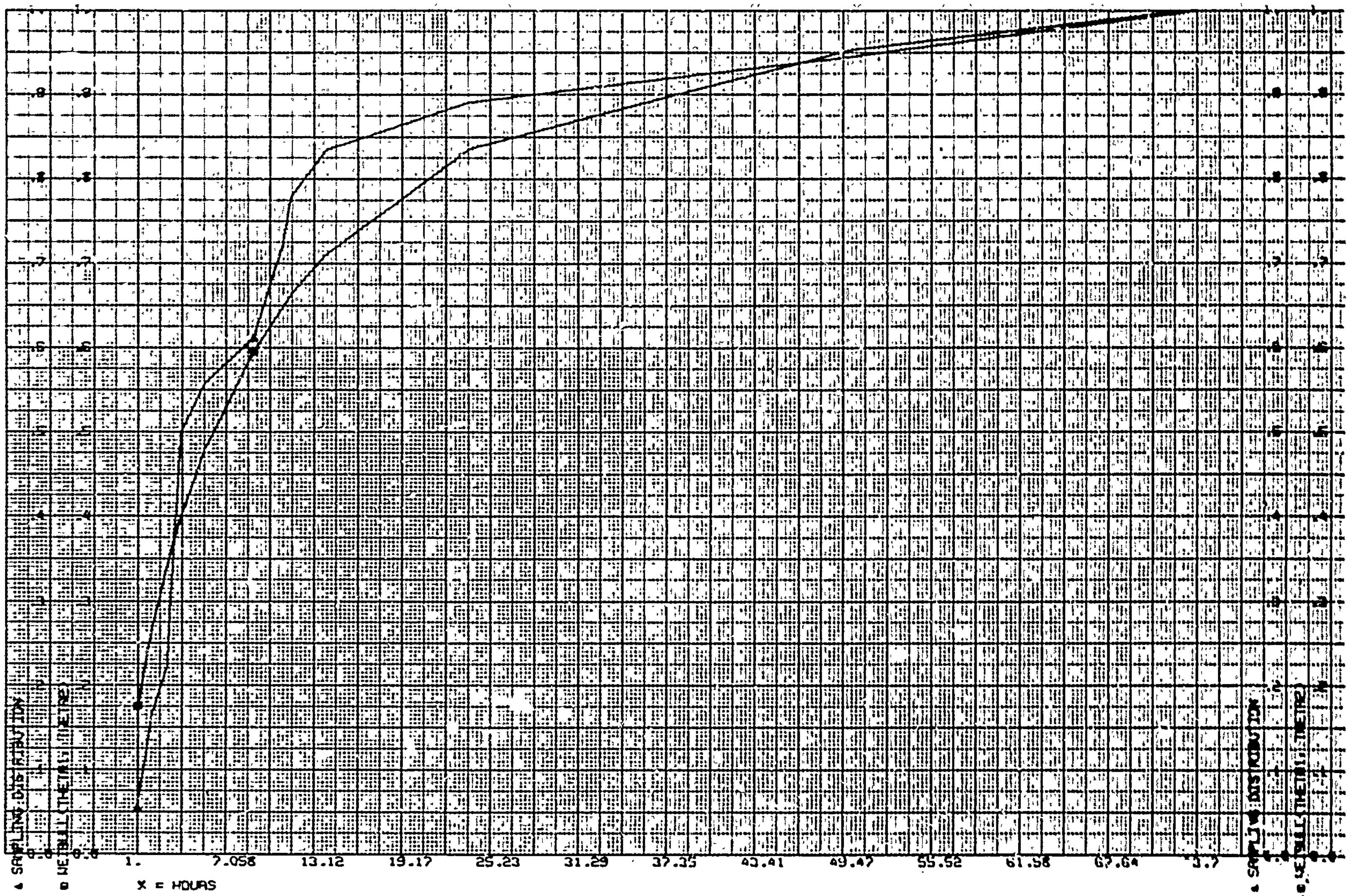

Figure 9. Test for Weibull Data: Critical LRU - Transmitter/Receiver, Shop Man Hours WUC 73CAO

Table 2: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}: S_n(t) \equiv F(t \mid \theta)$	Sample Size	$\bar{t}$	s_t	Graph	D_n	$1 - Q(D_n\sqrt{n})$	Decision
Transmitter/Receiver WUC 73CAO Line Active Hours	L(N(0,1))	12	-	-	10	0.4621	0.0118	Reject
	L(N(1.05, 0.87))	12	-	-	10	0.1008	0.9997	
	E(0.2056)	12	4.46	5.41	11	0.1821	0.8209	
	W(0.8260, 0.3167)	12	4.46	5.41	12	0.2378	0.5059	
Line Elapsed Hours	L(N(0,1)	12	-	-	13	0.6763	0.0000	Reject
	L(N(2.35, 2.02))	12	-	-	13	0.1517	0.9454	
	E(0.0356)	12	25.72	40.32	14	0.3075	0.2066	
	W(0.6590, 0.1431)	12	25.72	40.32	15	0.1759	0.8518	
Line Man Hours	L(N(0,1))	12	-	-	16	0.6181	0.0002	Reject
	L(N(1.62, 1.76))	12	-	-	16	0.1743	0.8591	
	E(0.0648)	12	14.14	30.51	17	0.3760	0.0671	
	W(0.5130, 0.3580)	12	14.14	30.51	18	0.2733	0.3313	

Source: 258 Data System for the F-111, Edwards AFB, California.

See footnote Table 1 for definition of $L(N(\mu,\sigma^2))$, $E(\lambda)$ and $W(\beta,\lambda)$.

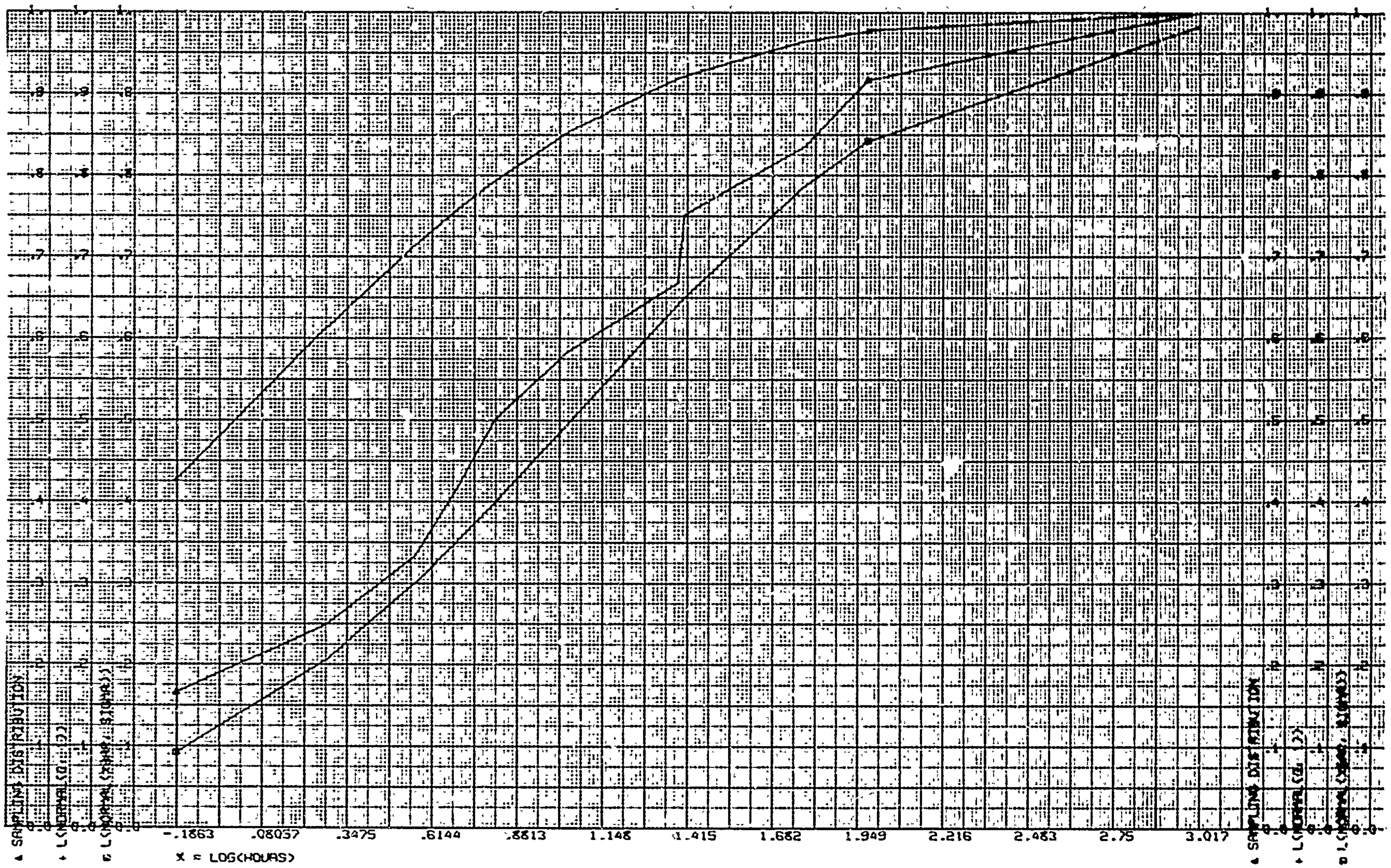

Figure 10. Test for Log Normality: Critical LRU - Transmitter/Receiver, Line Active Hours WUC 73CAO

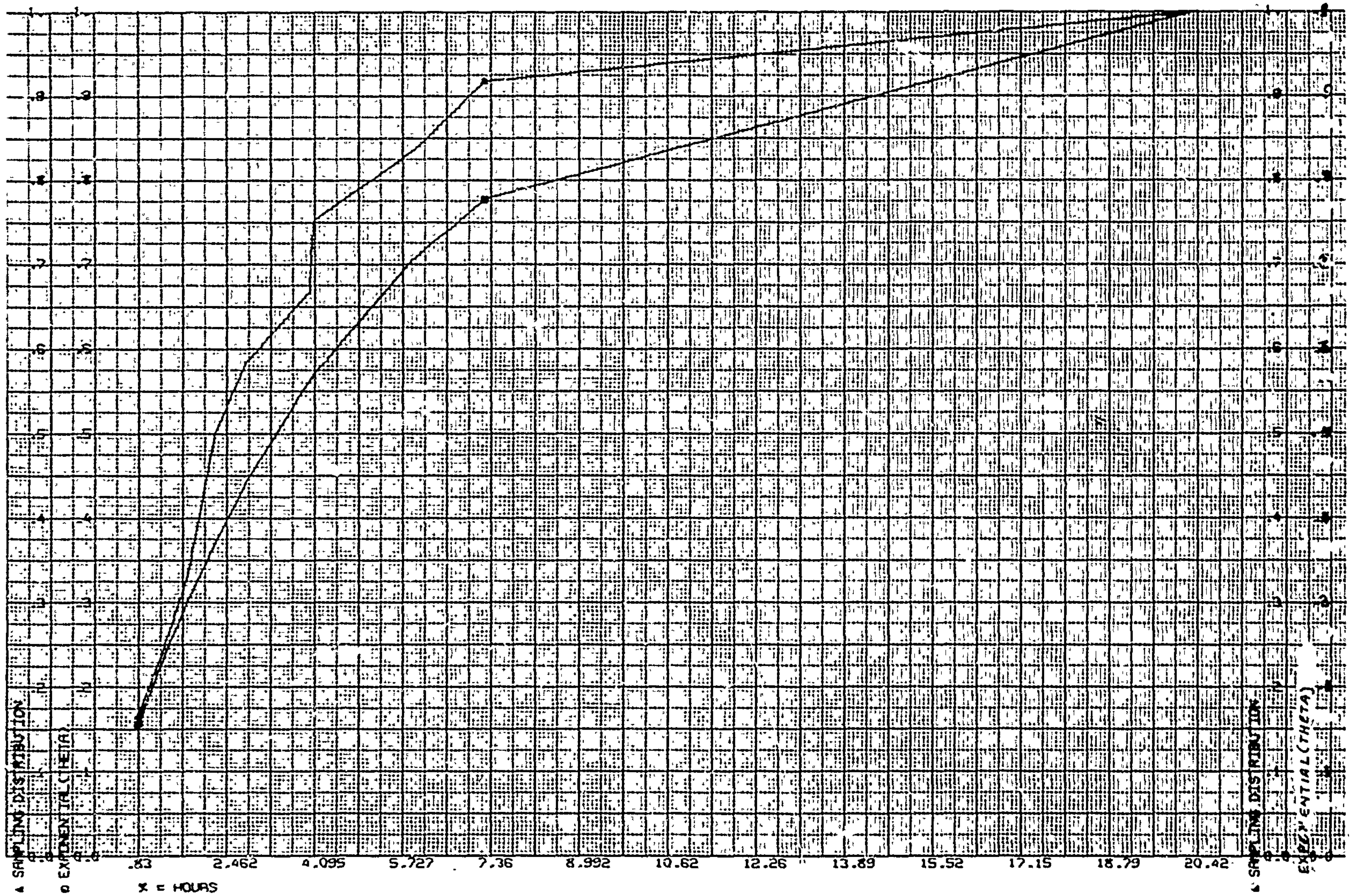

Figure 11. Test for Exponential Data: Critical LRU - Transmitter/Receiver, Line Active Hours WUC 73CAO

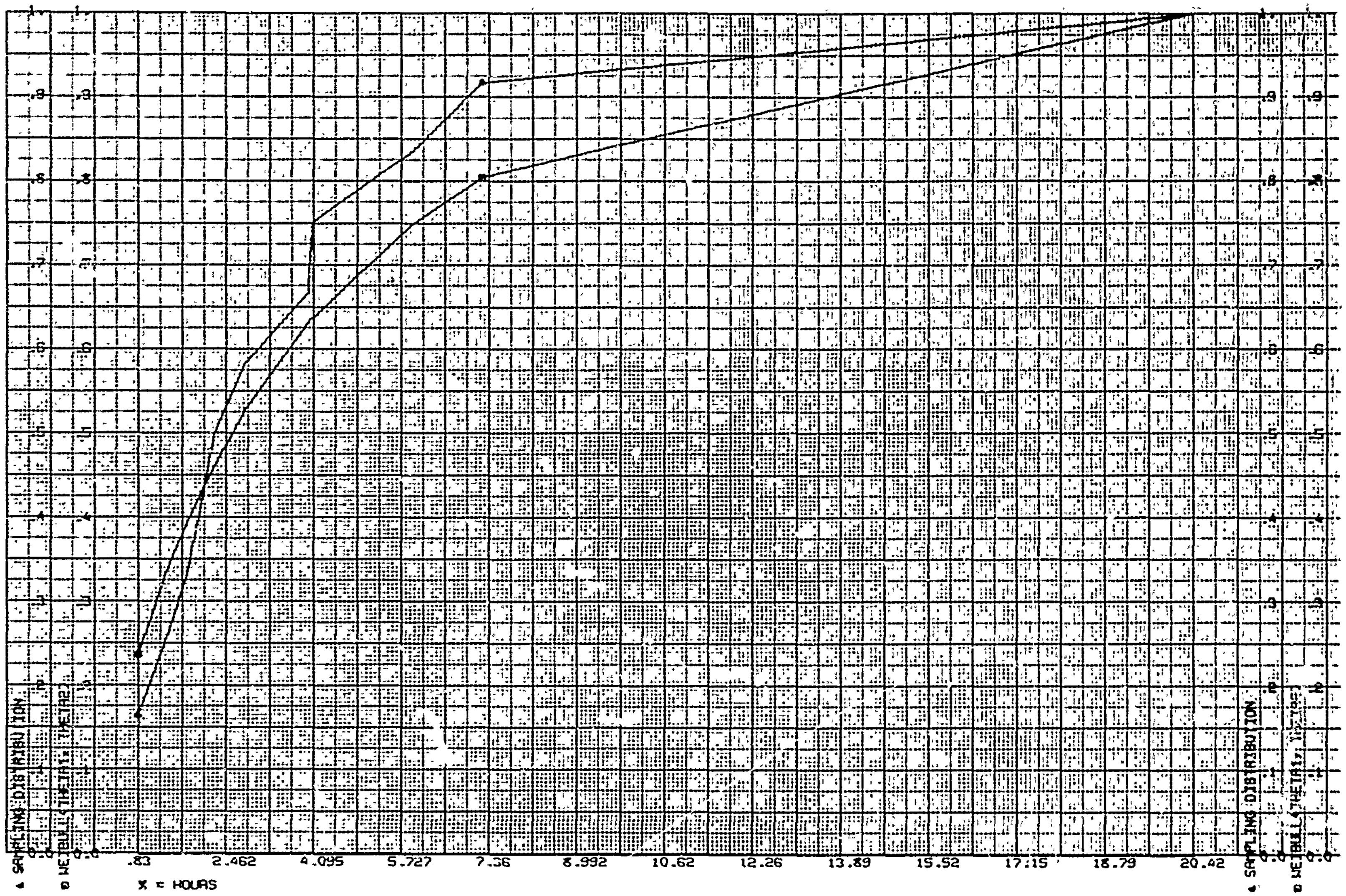

Figure 12. Test for Weibull Data: Critical LRU Transmitter/Receiver, Line Active Hours WUC 73CAO

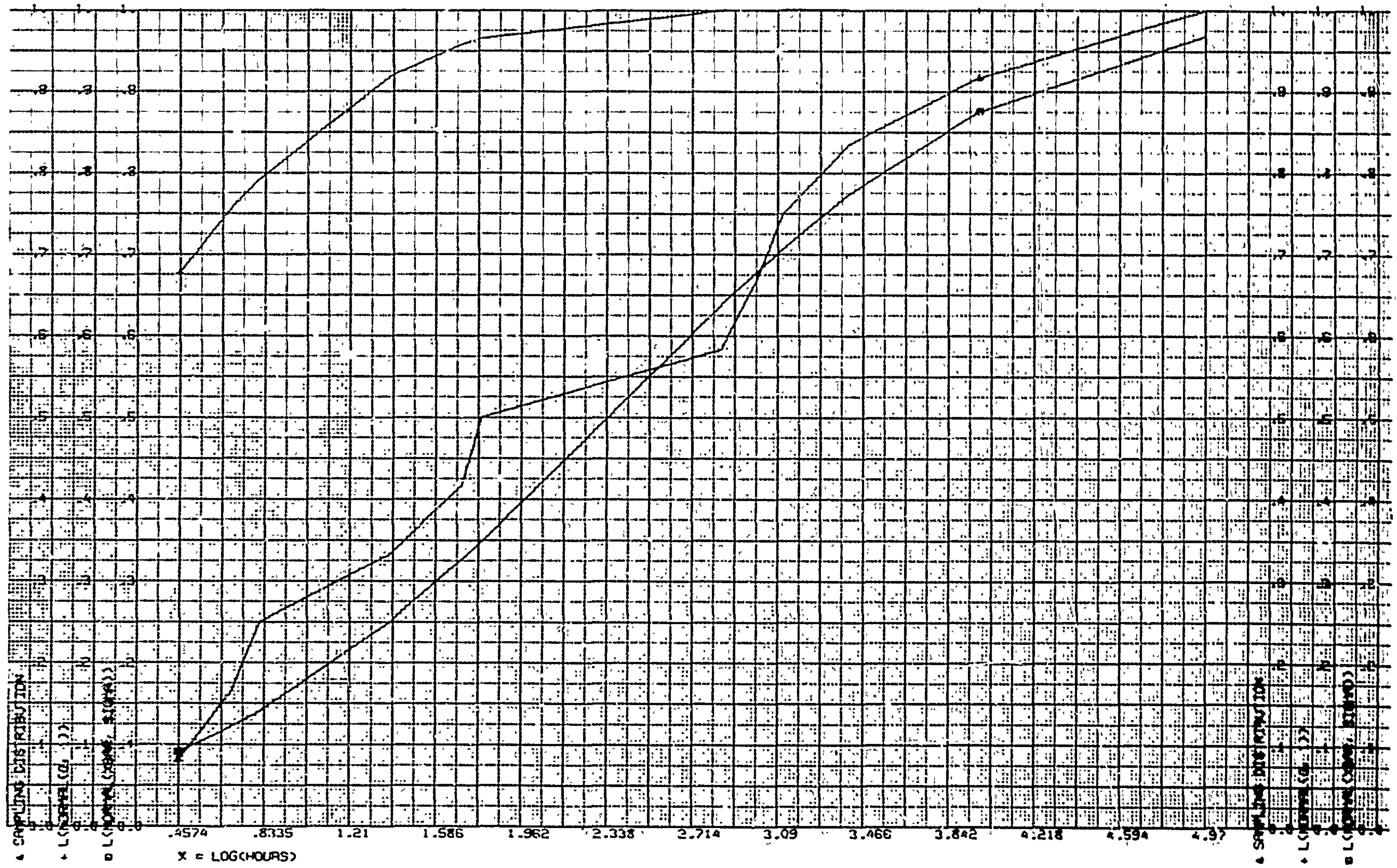

Figure 13. Test for Log Normality: Critical LRU - Transmitter/Receiver; Line Elapsed Hours WUC 73CAO

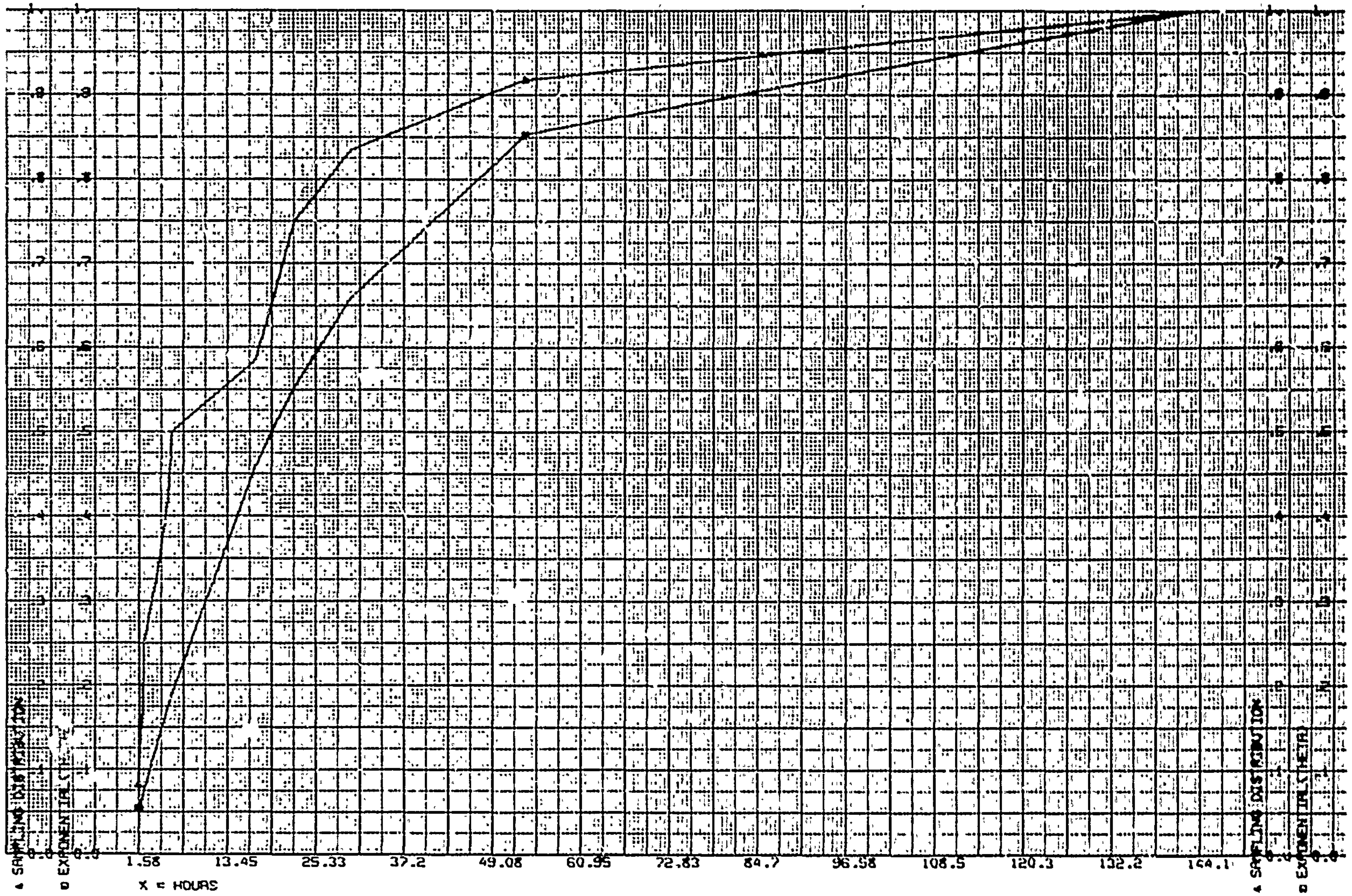

Figure 14. Test for Exponential Data: Critical LRU - Transmitter/Receiver, Line Elapsed Hours
WUC 73CAO

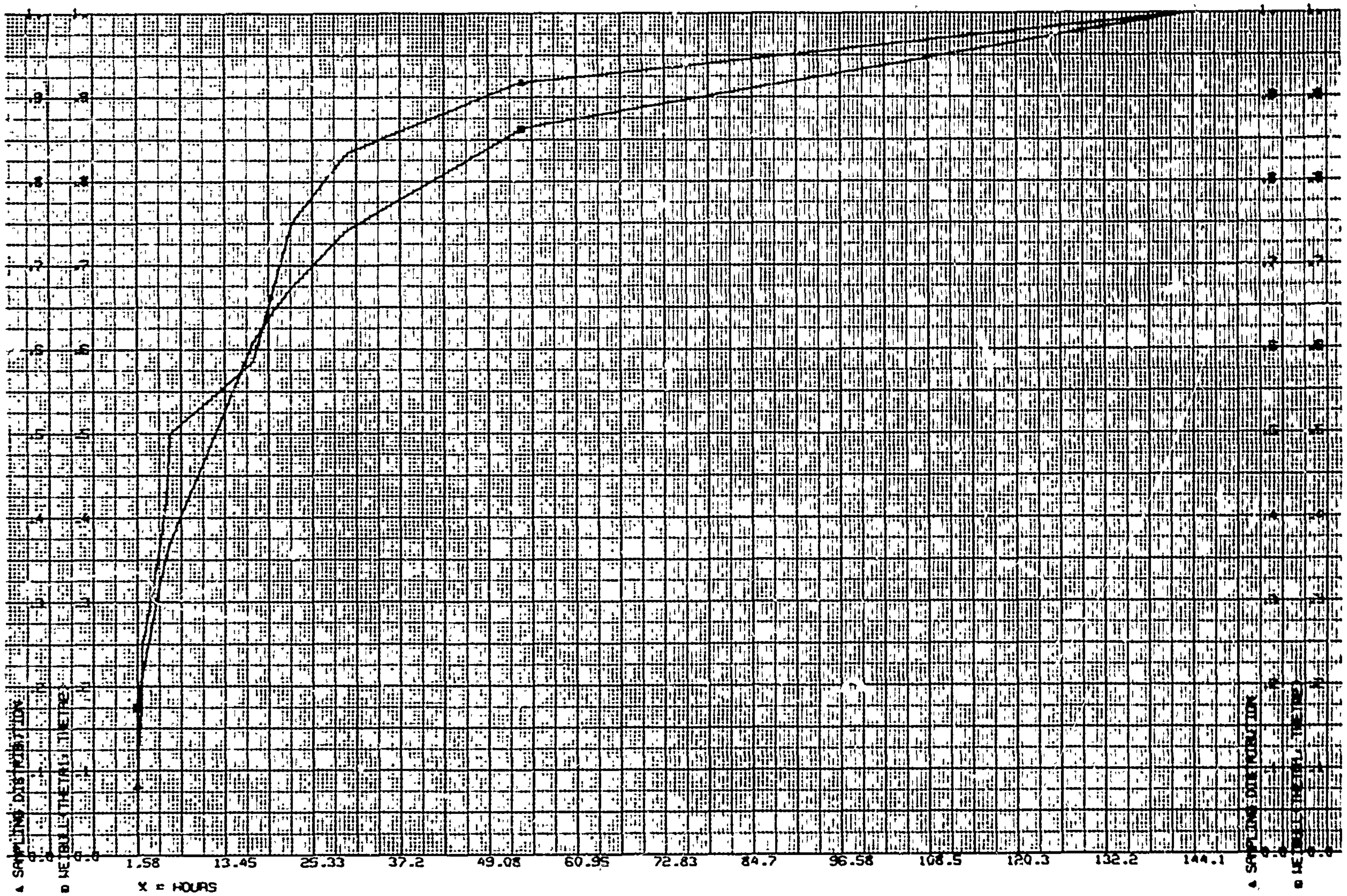

Figure 15. Test for Weibull Data: Critical LRU - Transmitter/Receiver, Line Elapsed Hours WUC 73CAO

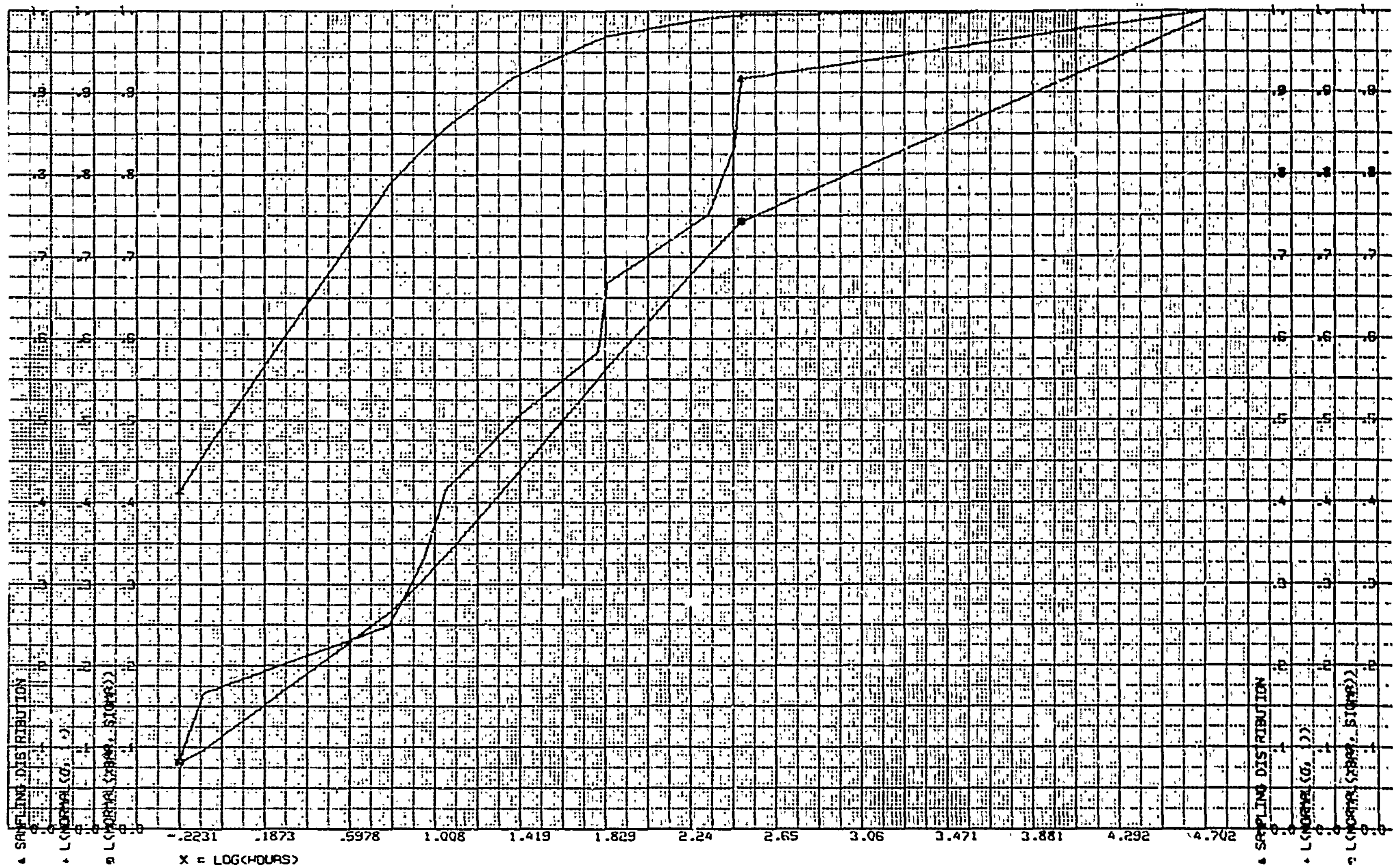

Figure 16. Test for Log Normality: Critical LRU - Transmitter/Receiver, Line Man Hours WUC 73CAO

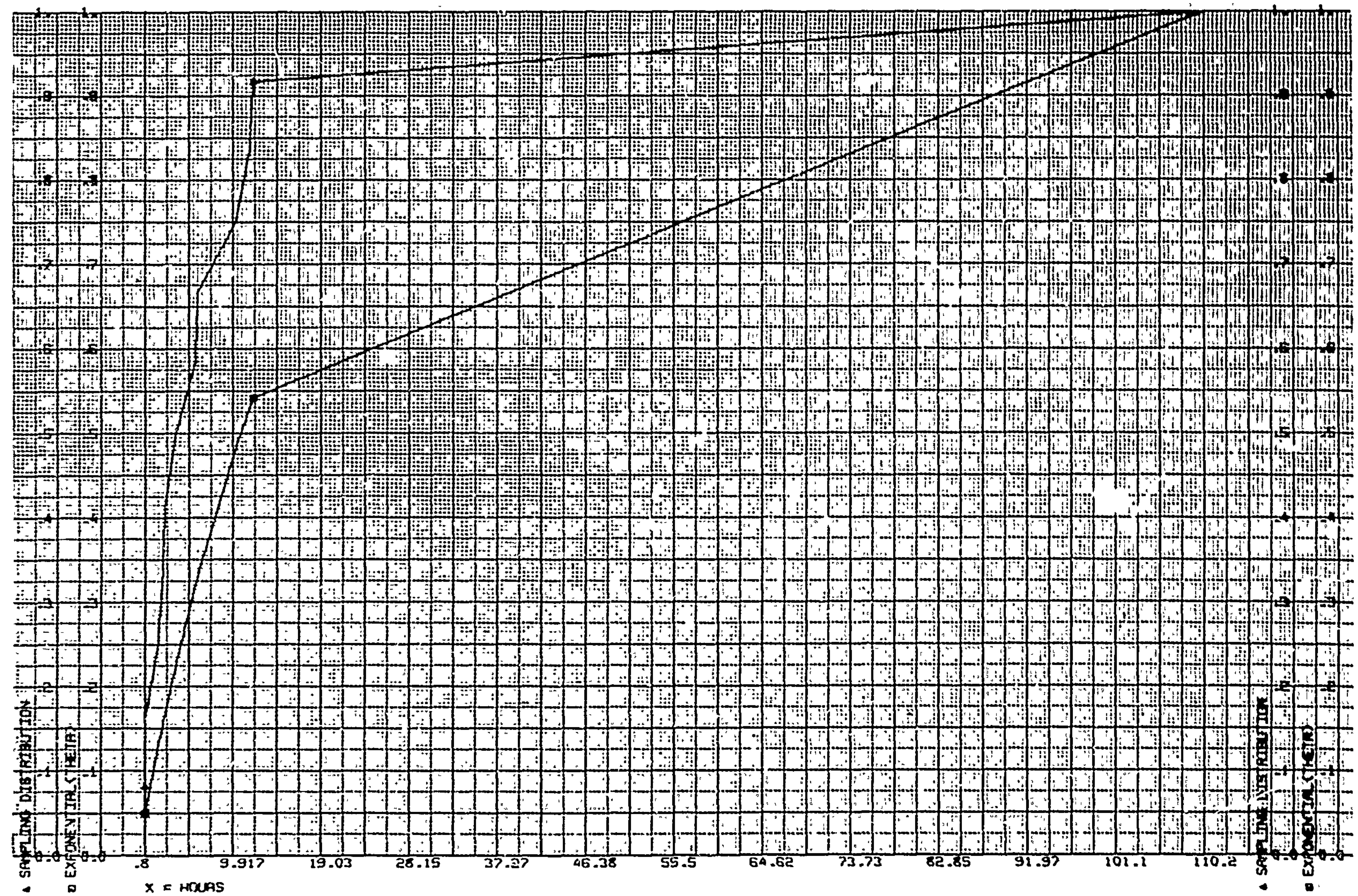

Figure 17. Test for Exponential Data: Critical LRU - Transmitter/Receiver, Line Man Hours WUC 73CAO

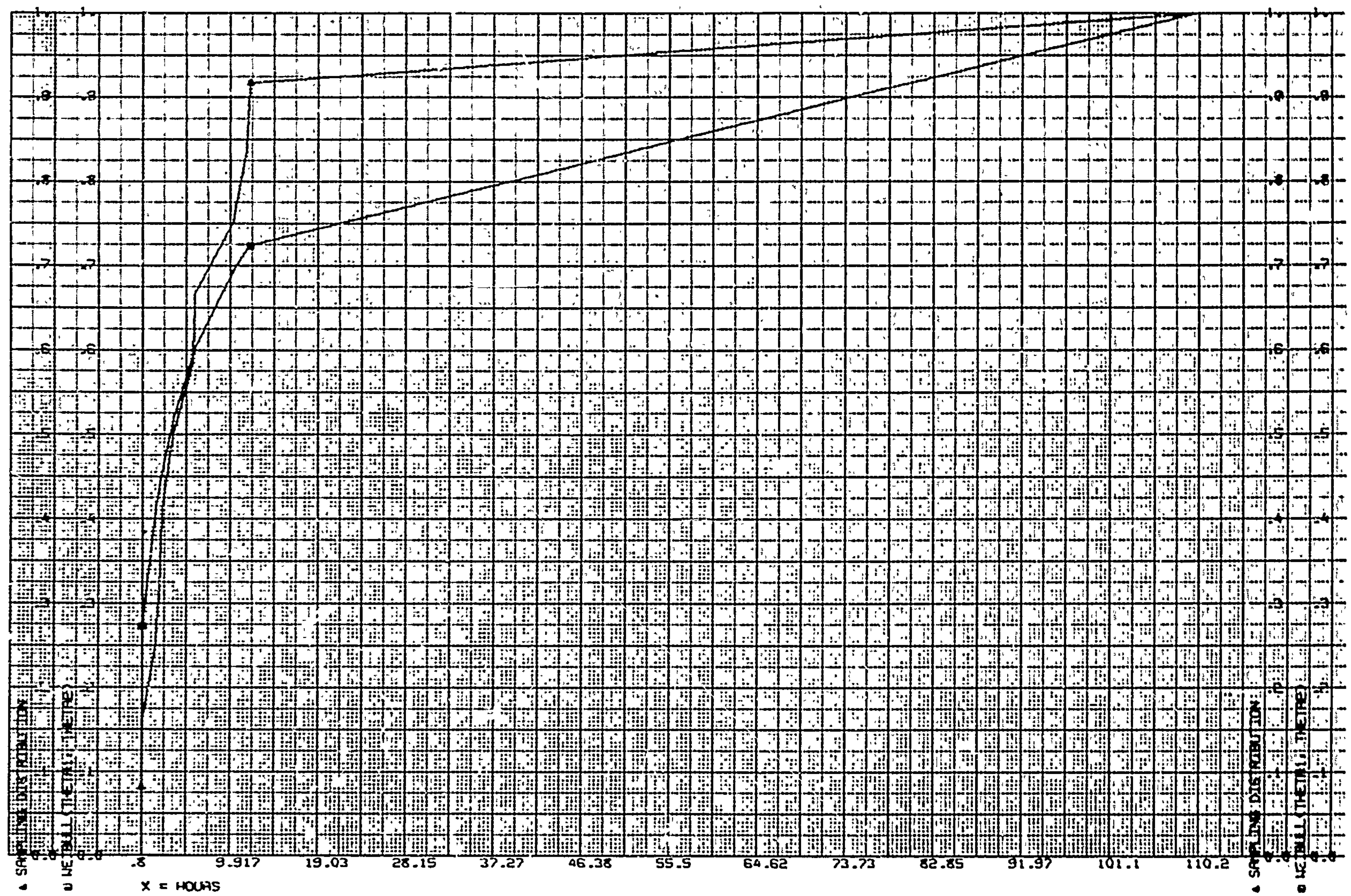

Figure 18. Test for Weibull Data: Critical LRU - Transmitter/Receiver, Line Man Hours WUC 73CAO

Table 3: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}: S_n(t) \equiv F(t \mid \theta)$	Sample Size	$\bar{t}$	s_t	Graph	D_n	$1 - Q(D_n\sqrt{n})$	Decision
Modulator Receiver/Transmitter WUC 73BDO Shop Active Hours	L(N(0,1))	40	-	-	19	0.6390	0.0000	Reject
	L(N(1.56, 1.30))	40	-	-	19	0.1187	0.6257	
	E(0.1104)	40	8.83	14.73	20	0.1239	0.5722	
	W(0.6250, 0.3205)	40	8.83	14.73	21	0.2461	0.0158	
Shop Elapsed Hours	L(N(0,1))	40	-	-	22	0.7140	0.0000	Reject
	L(N(1.91. 1.74)	40	-	-	22	0.1205	0.6065	
	E(0.0574)	40	16.98	36.41	23	0.2519	0.0125	Reject
	W(0.5100, 0.3298)	40	16.98	36.91	24	0.2887	0.0025	Reject
Shop Man Hours	L(N(0,1))	40	-	-	25	0.6884	0.0000	Reject
	L(N(2.05, 1.77))	40	-	-	25	0.1597	0.2597	
	E(0.0685)	40	14.23	13.71	26	0.0900	0.9020	
	W(1.0330, 0.0635)	40	14.23	13.71	27	0.0959	0.8553	

Source: 258 Data System for the F-111, Edwards AFB, California

See footnote Table 1 for definition of $L(N(\mu,\sigma^2))$, $E(\lambda)$ and $W(\beta,\lambda)$.

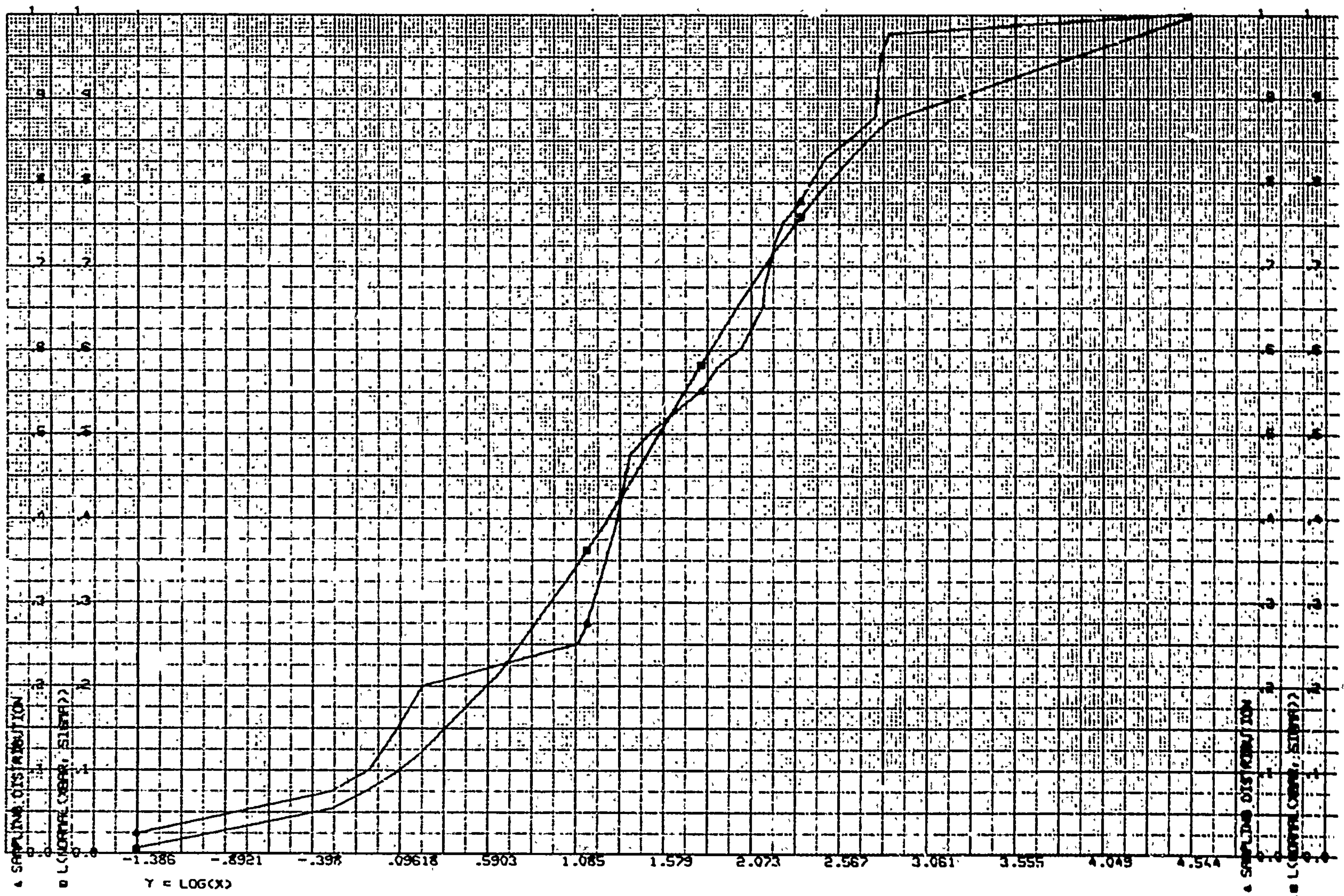

Figure 19. Test for Log Normality: Critical LRU - Modulator, Receiver/Transmitter, Shop Active Hours WUC 73BDO

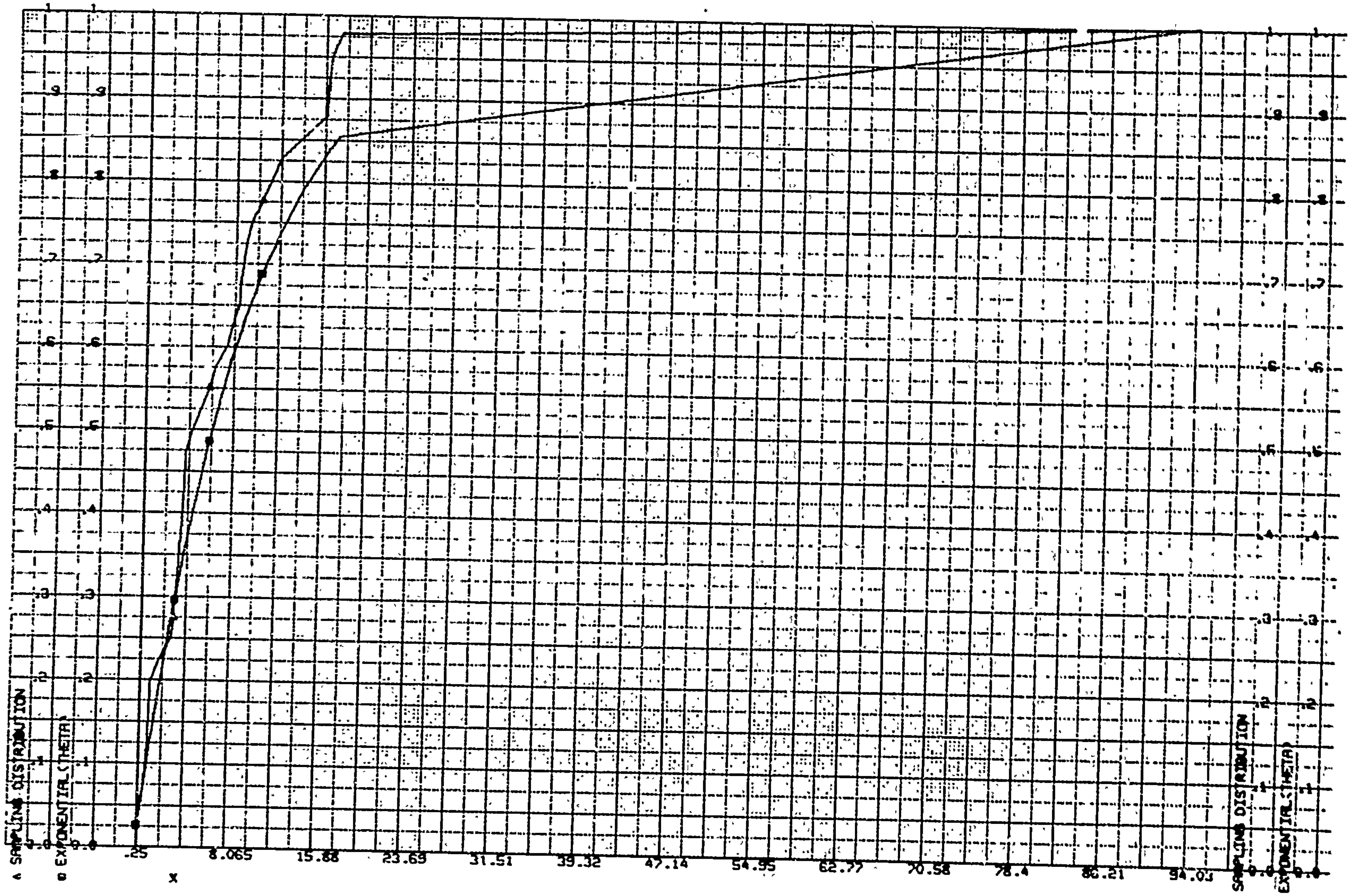

Figure 20. Test for Exponential Data: Critical LRU - Modulator, Receiver/Transmitter, Shop Active Hours WUC 73BDO

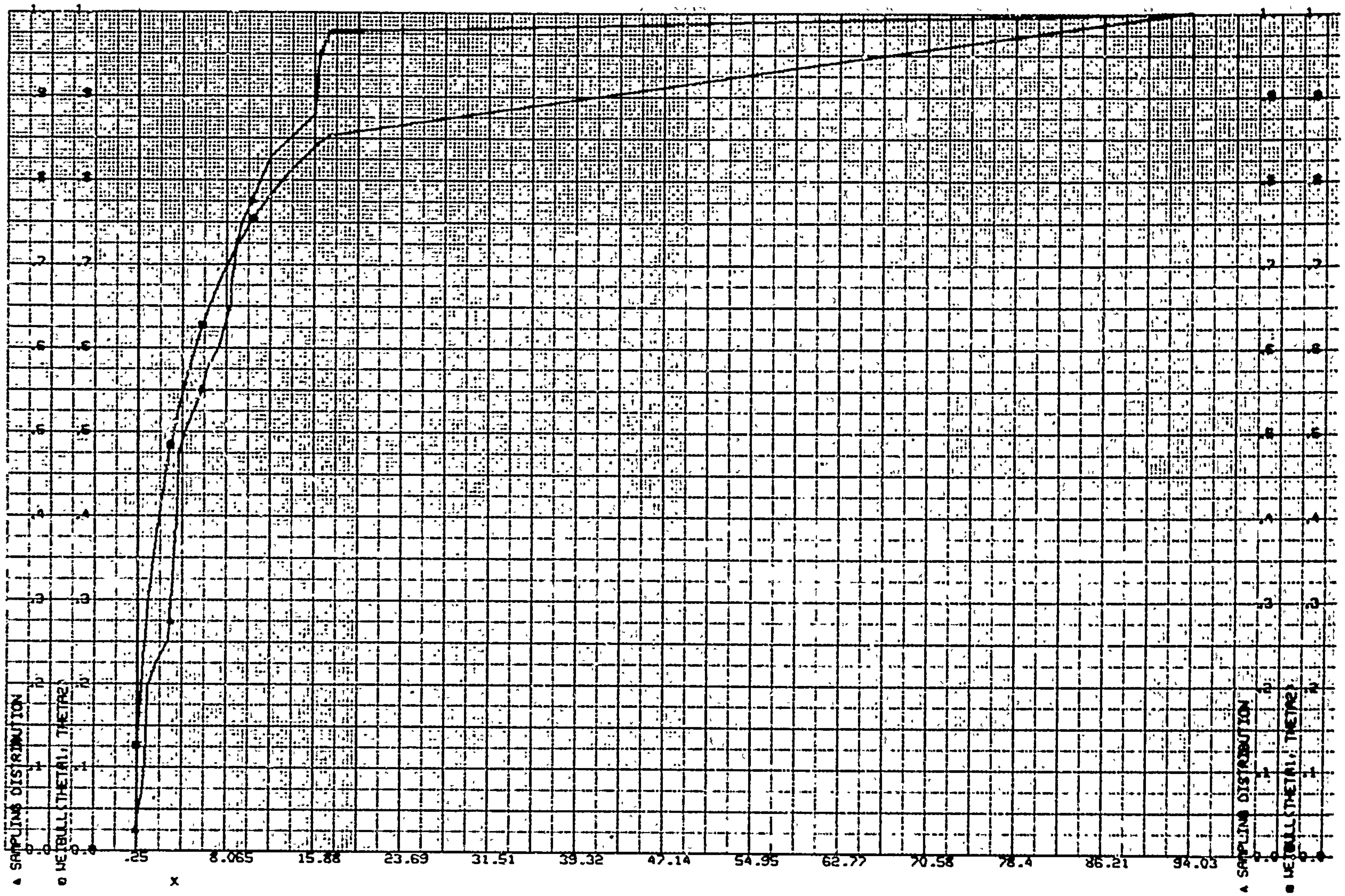

Figure 21. Test for Weibull Data: Critical LRU - Modulator, Receiver/Transmitter, Shop Active Hours WUC 73BDO

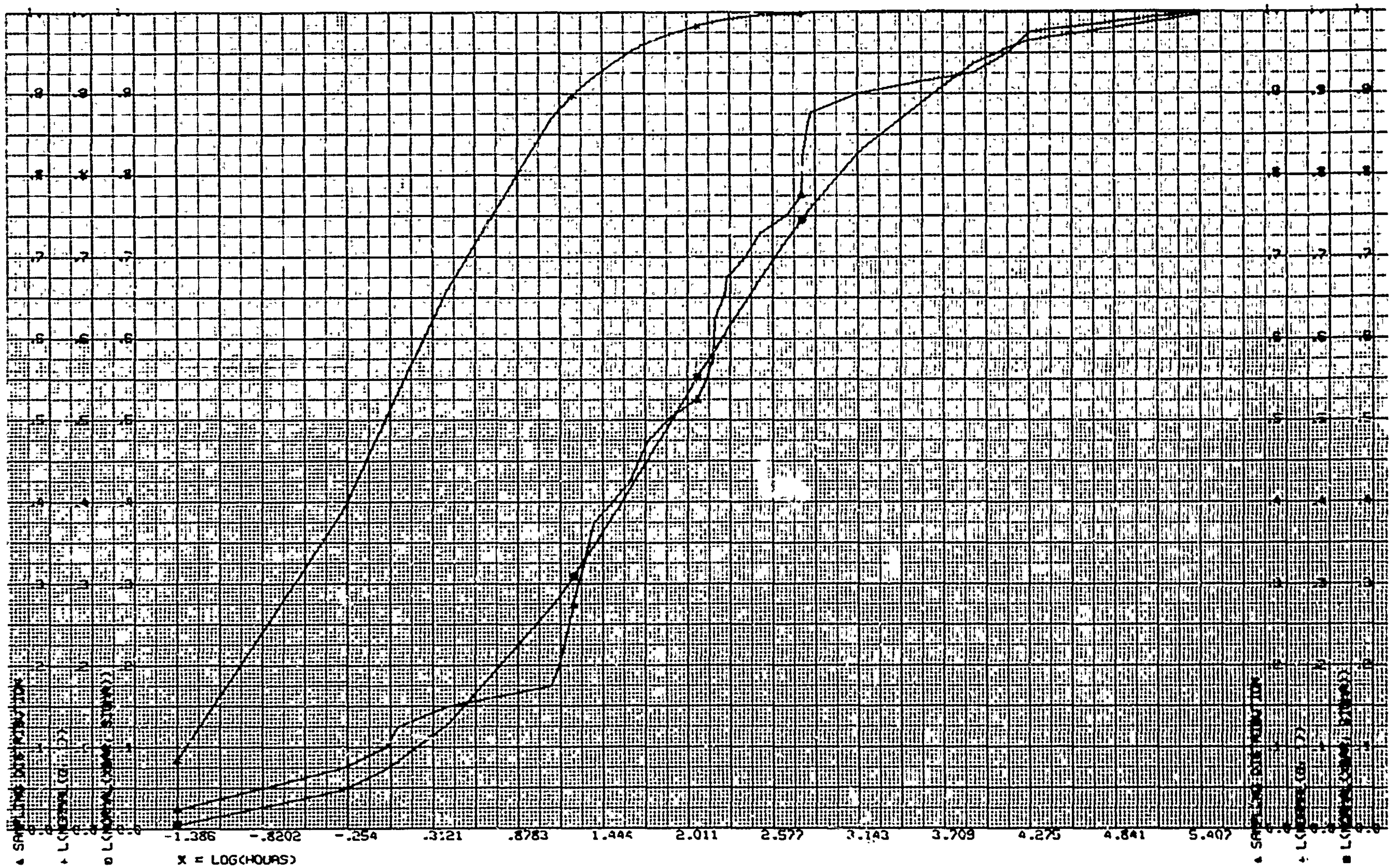

Figure 22. Test for Log Normality: Critical LRU - Modulator, Receiver/Transmitter, Shop Elapsed Hours WUC 73BDO

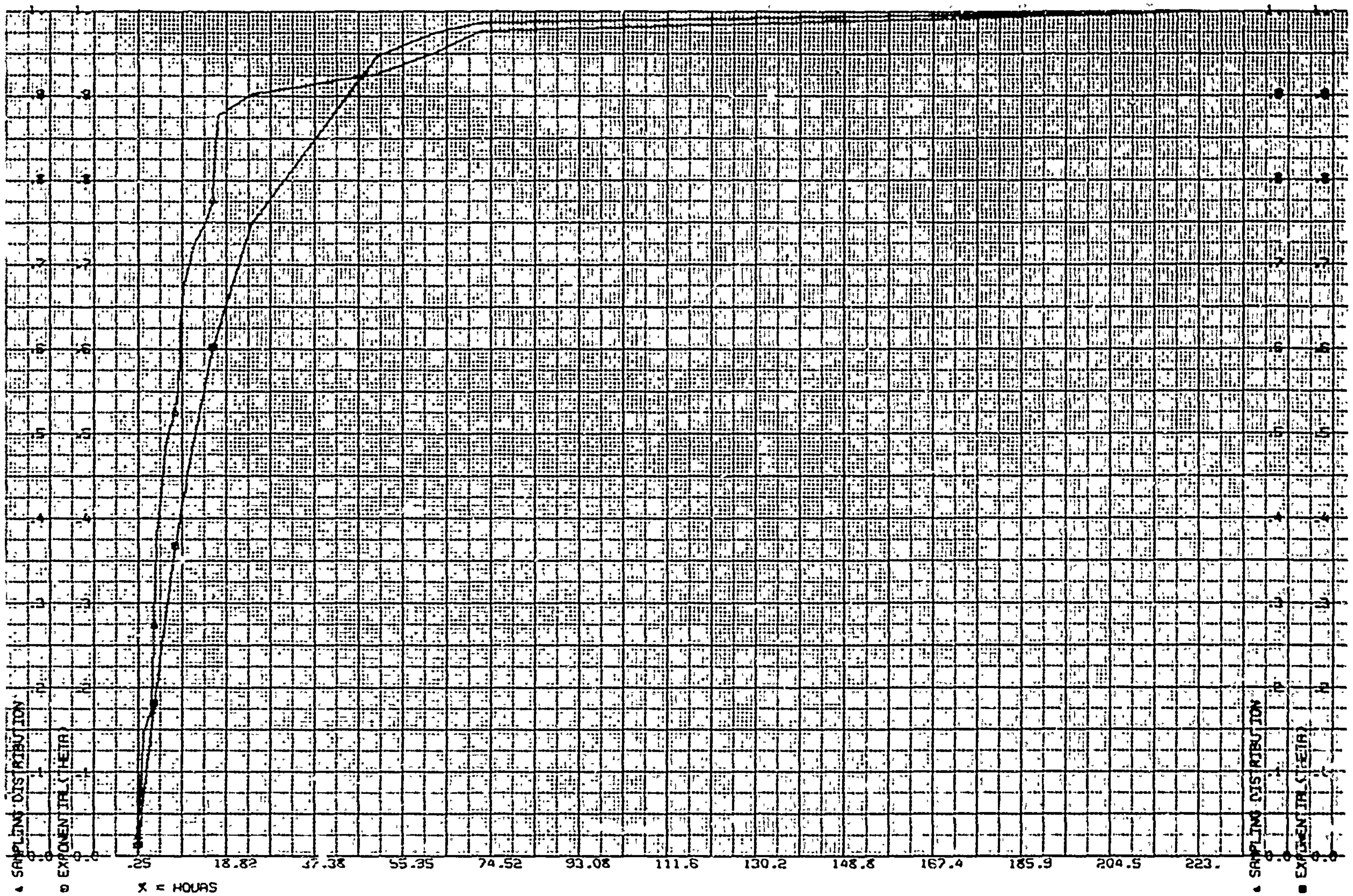

Figure 23. Test for Exponential Data: Critical LRU - Modulator, Receiver/Transmitter, Shop Elapsed Hours WUC 73BDO

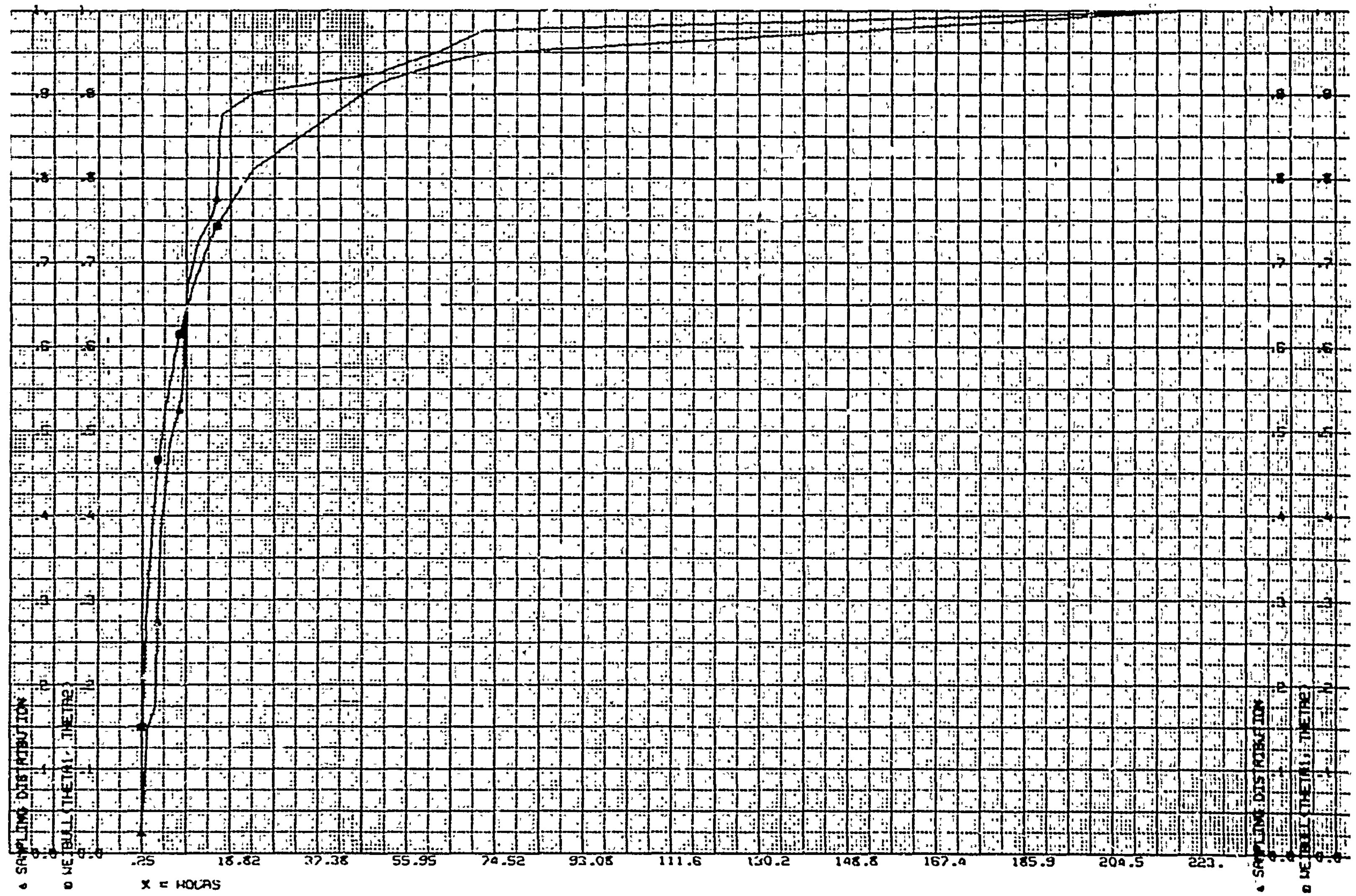

Figure 24. Test for Weibull Data: Critical LRU - Modulator, Receiver/Transmitter, Shop Elapsed Hours WUC 73BDO

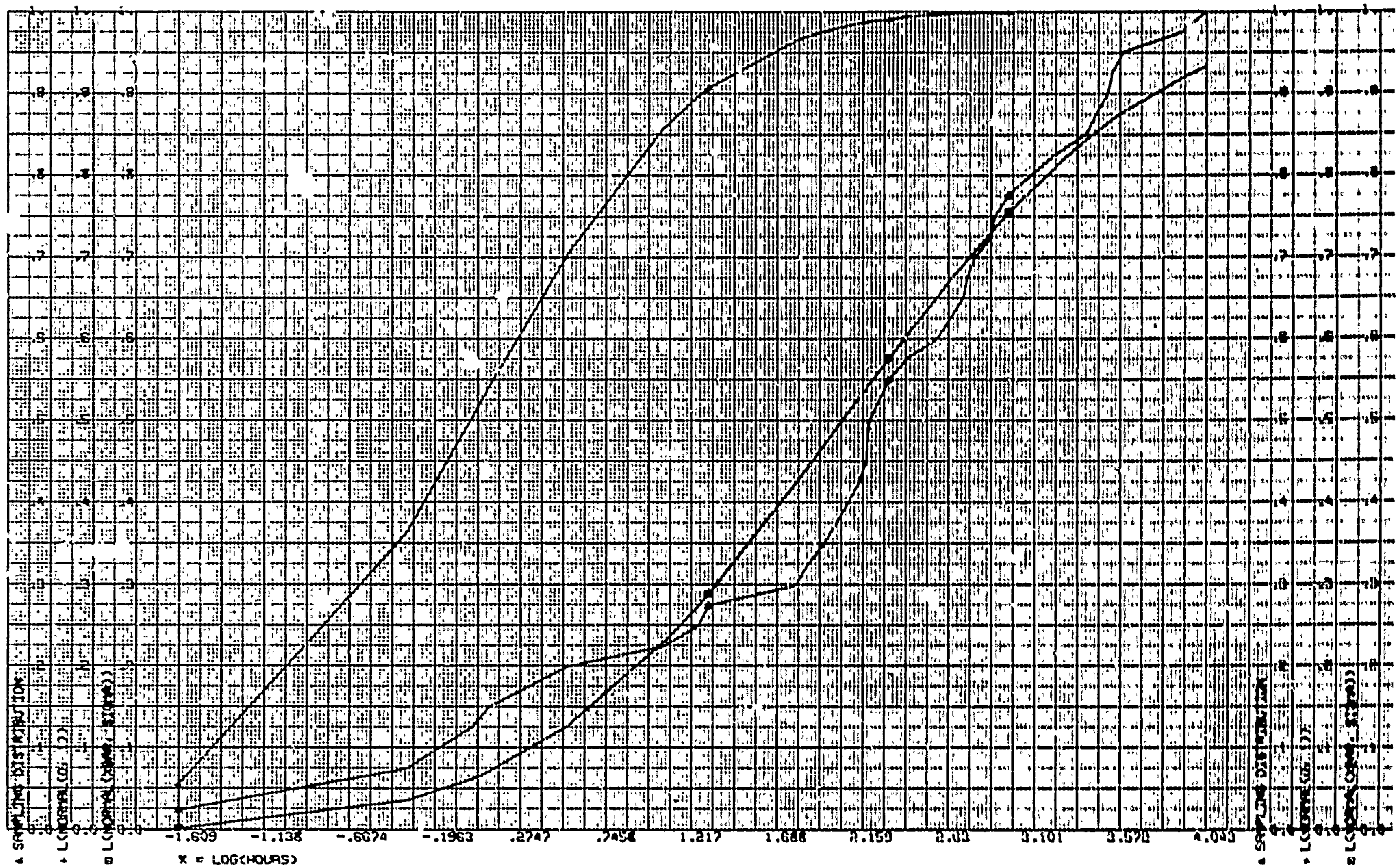

Figure 25. Test for Log Normality: Critical LRU - Modulator, Receiver/Transmitter, Sh.^· Man·Hours WUC 73BDO

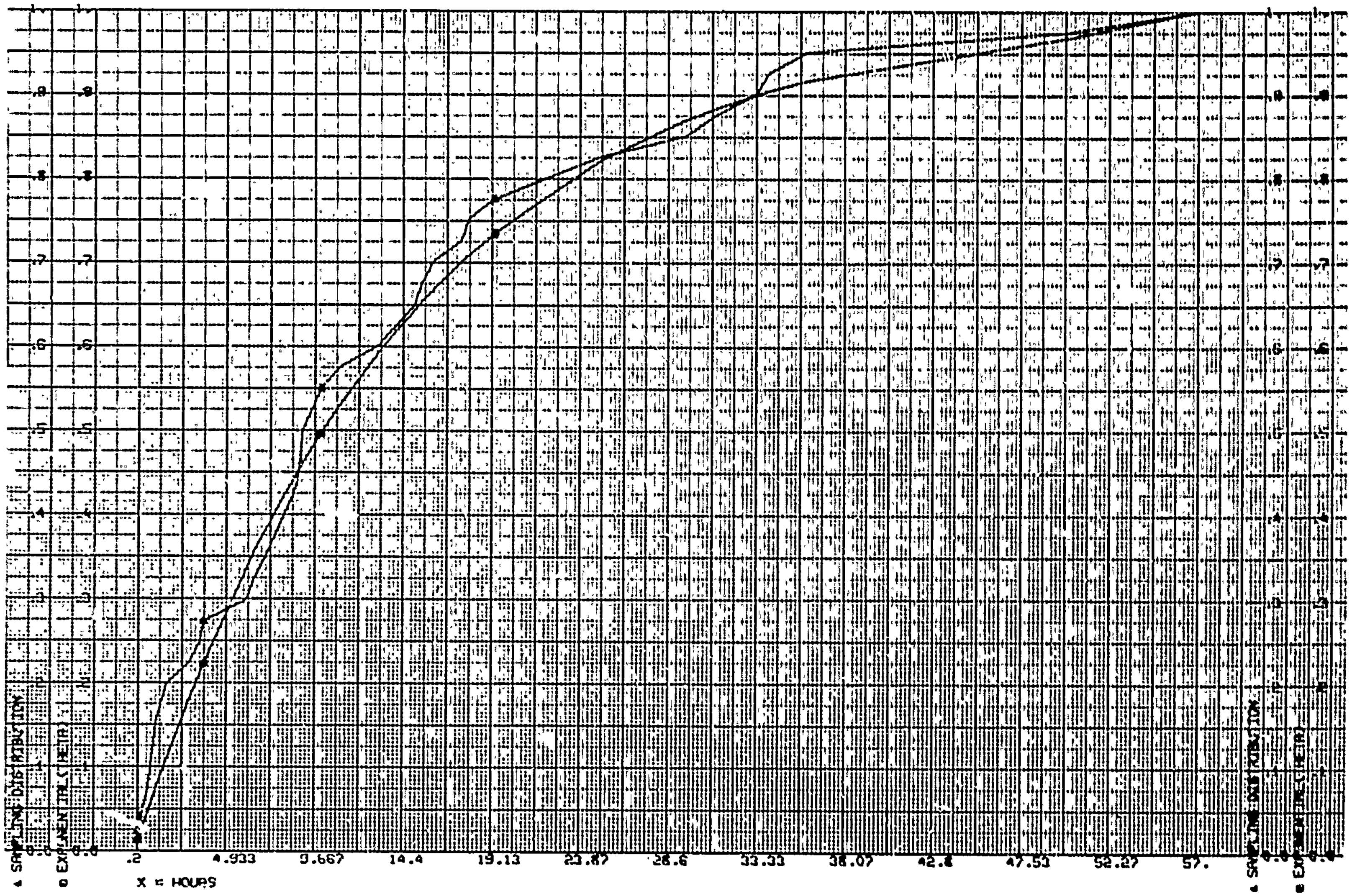

Figure 26. Test for Exponential Data: Critical LRU - Modulator, Receiver/Transmitter, Shop Man Hours WUC 73BDO

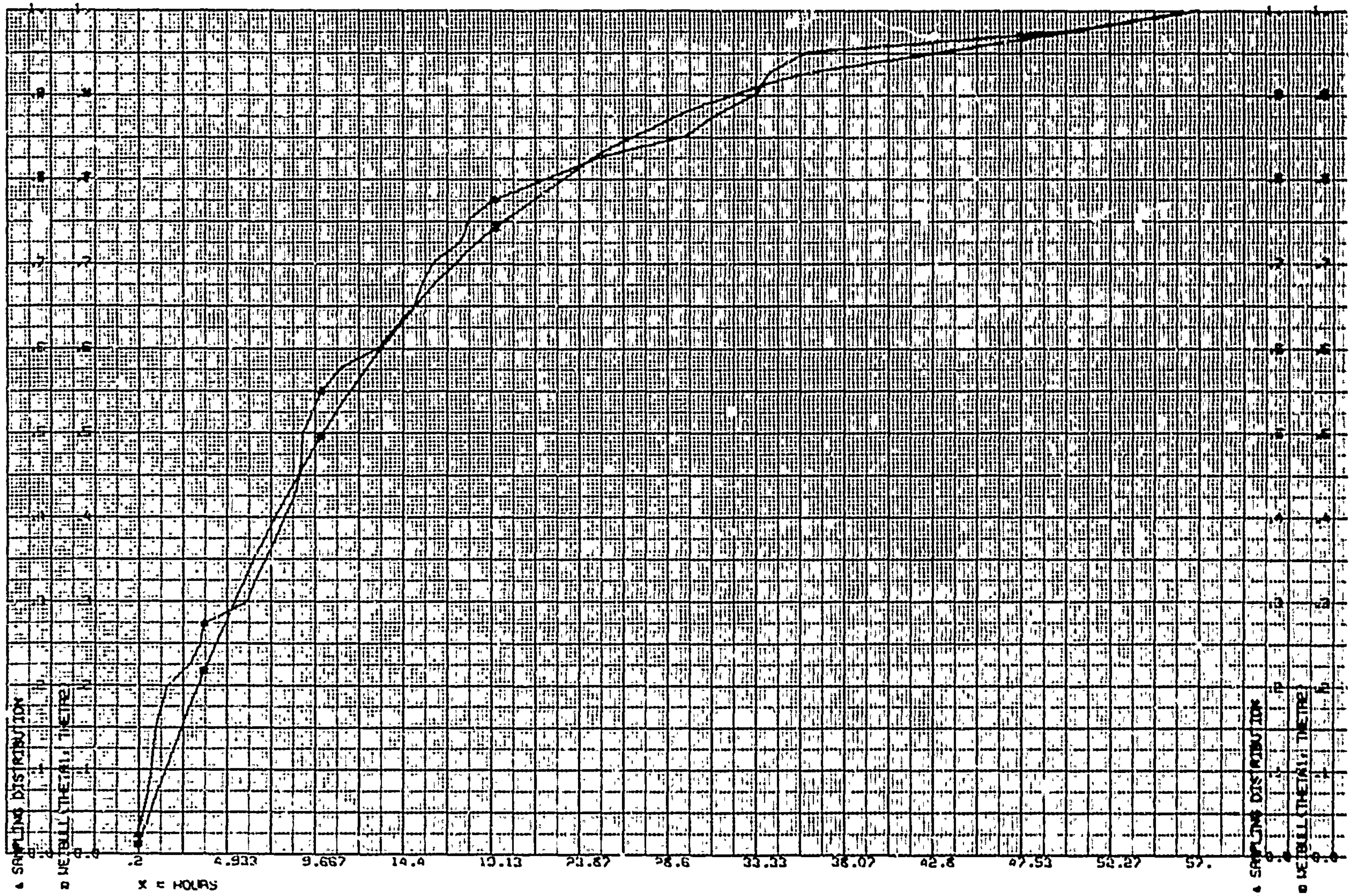

Figure 27. Test for Weibull Data: Critical LRU - Modulator, Receiver/Transmitter, Shop Man Hours WUC 73BDO

Table 4: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}: S_n(t) \equiv F(t\|\theta)$	Sample Size	$\bar{t}$	s_t	Graph	D_n	$1 - Q(D_n\sqrt{n})$	Decision
Modulator Receiver/Transmitter WUC 73BDO Line Active Hours	L(N(0,1))	32	-	-	28	0.5623	0.0000	Reject
	L(N(1.07, 0.32))	32	-	-	28	0.0815	0.9836	
	E(0.2831)	32	3.42	2.11	29	0.2819	0.0124	Reject
	W(1.6470, 0.1097)	32	3.42	2.11	30	0.1324	0.6289	
Line Elapsed Hours	L(N(0,1))	32	-	-	31	0.6765	0.0000	Reject
	L(N(2.62, 2.52))	32	-	-	31	0.1585	0.3971	
	E(0.0260)	32	37.28	49.35	32	0.2920	0.0085	Reject
	W(0.7640, 0.0712)	32	37.28	49.35	33	0.1999	0.1547	
Line Man Hours	L(N(0,1))	32	-	-	34	0.8093	0.0000	Reject
	L(N(1.94, 0.34))	32	-	-	34	0.1069	0.8583	
	E(0.1196)	32	8.10	4.47	35	0.2495	0.0372	Reject
	W(1.8520, 0.0167)	32	8.10	4.47	36	0.1209	0.7379	

Source: 258 Data System for F-111, Edwards AFB, California

See footnote Table 1 for definition of $L(N(\mu,\sigma^2))$, $E(\lambda)$ and $W(\theta,\lambda)$.

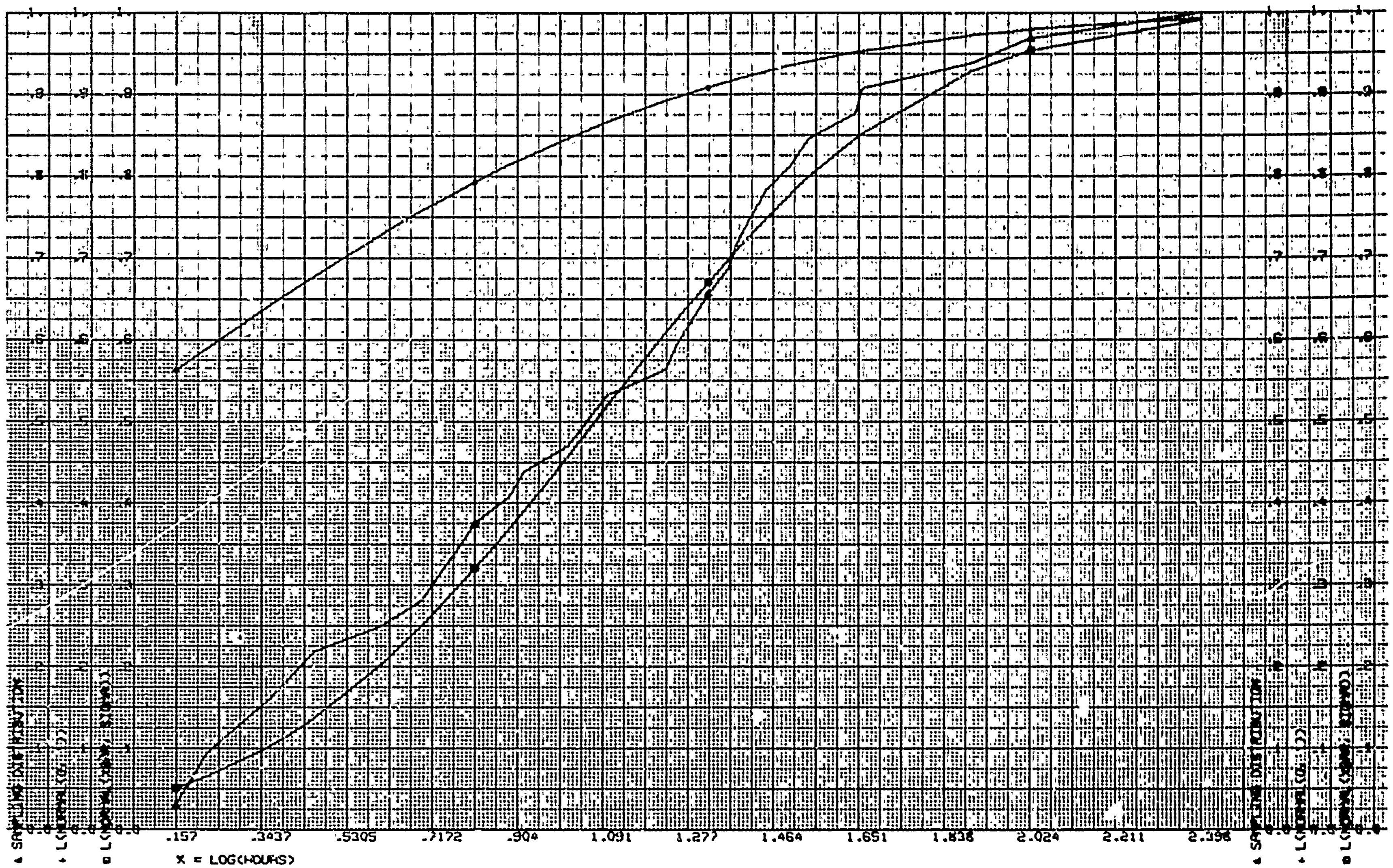

Figure 28. Test for Log Normality: Critical LRU - Modulator, Receiver/Transmitter, Line Active Hours WUC 73BDO

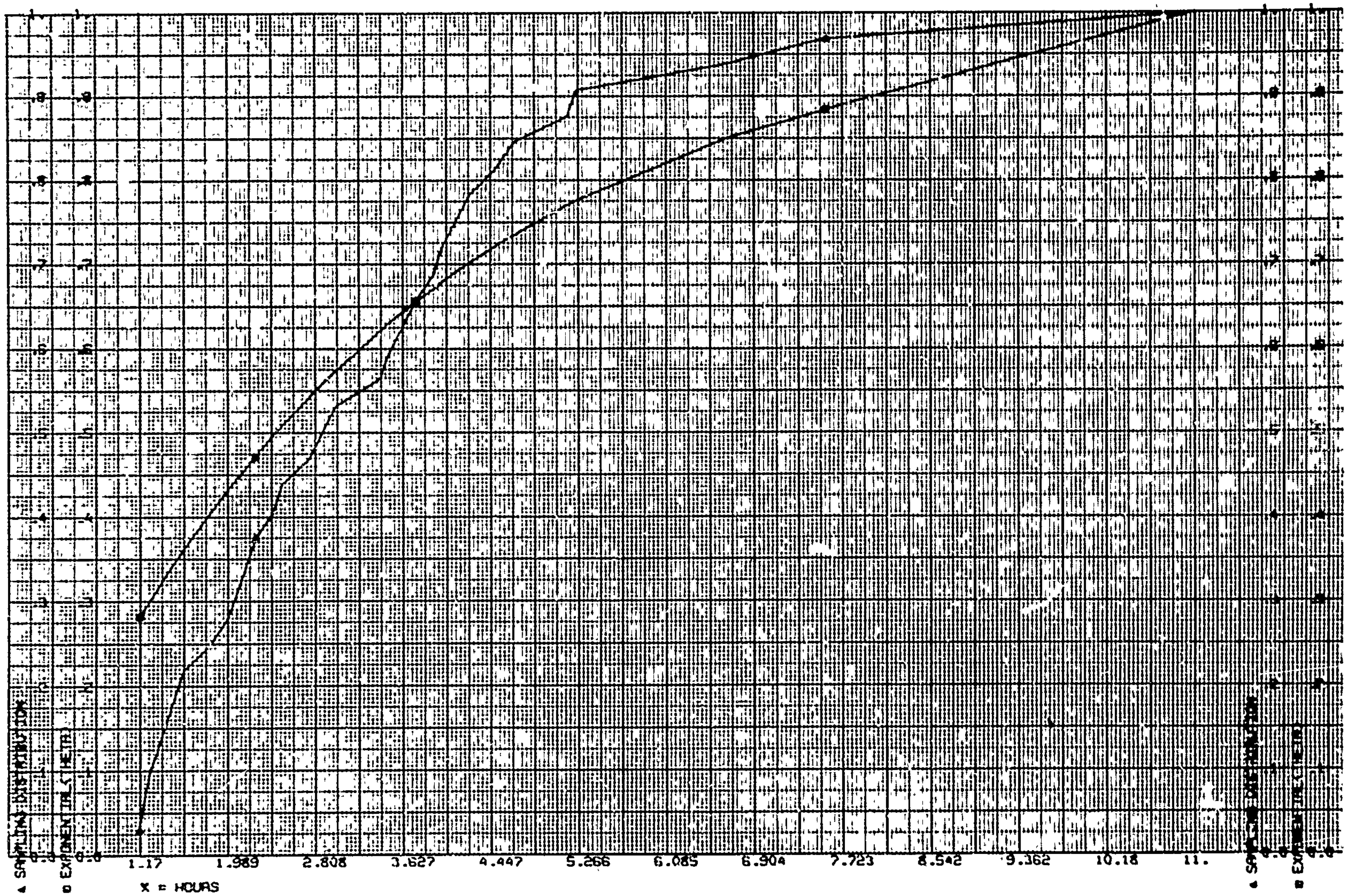

Figure 29. Test for Exponential Data: Critical LRU - Modulator, Receiver/Transmitter, Line Active Hours WUC 73BDO

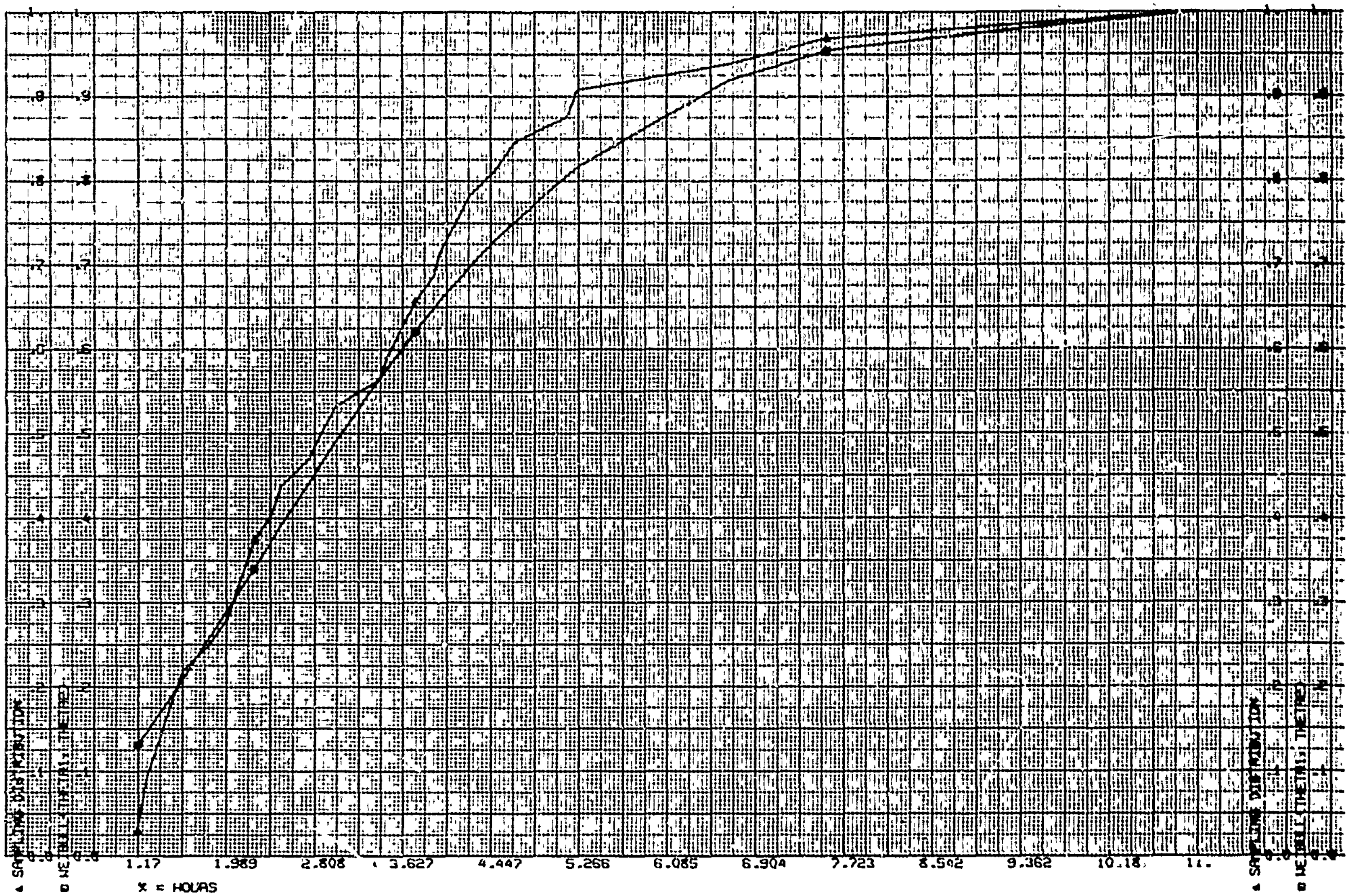

Figure 30. Test for Weibull Data: Critical LRU - Modulator, Receiver/Transmitter, Line Active Hours WUC 73BDO

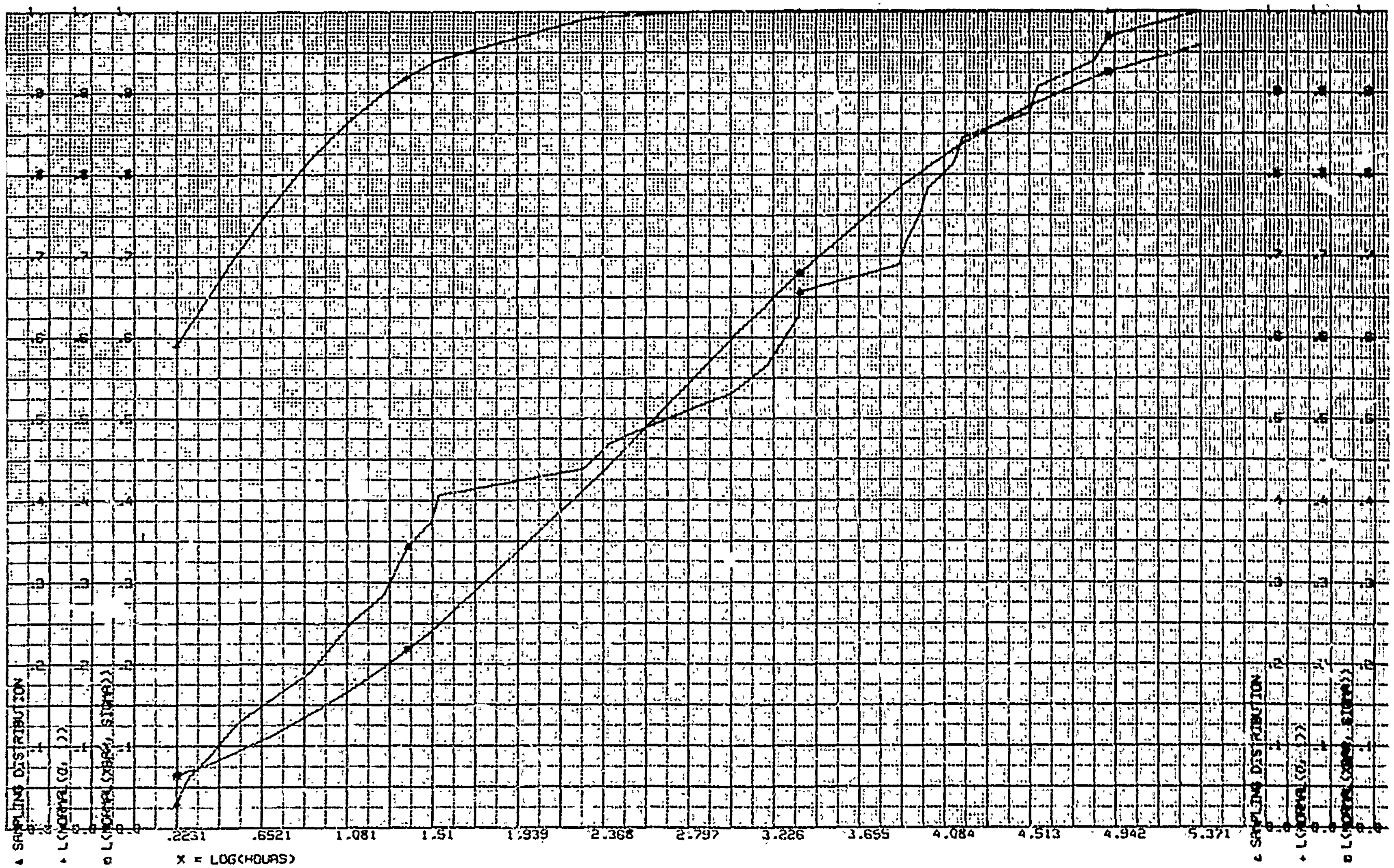

Figure 31. Test for Log Normality: Critical LRU - Modulator, Receiver/Transmitter, Line Elapsed Hours WUC 73EDO

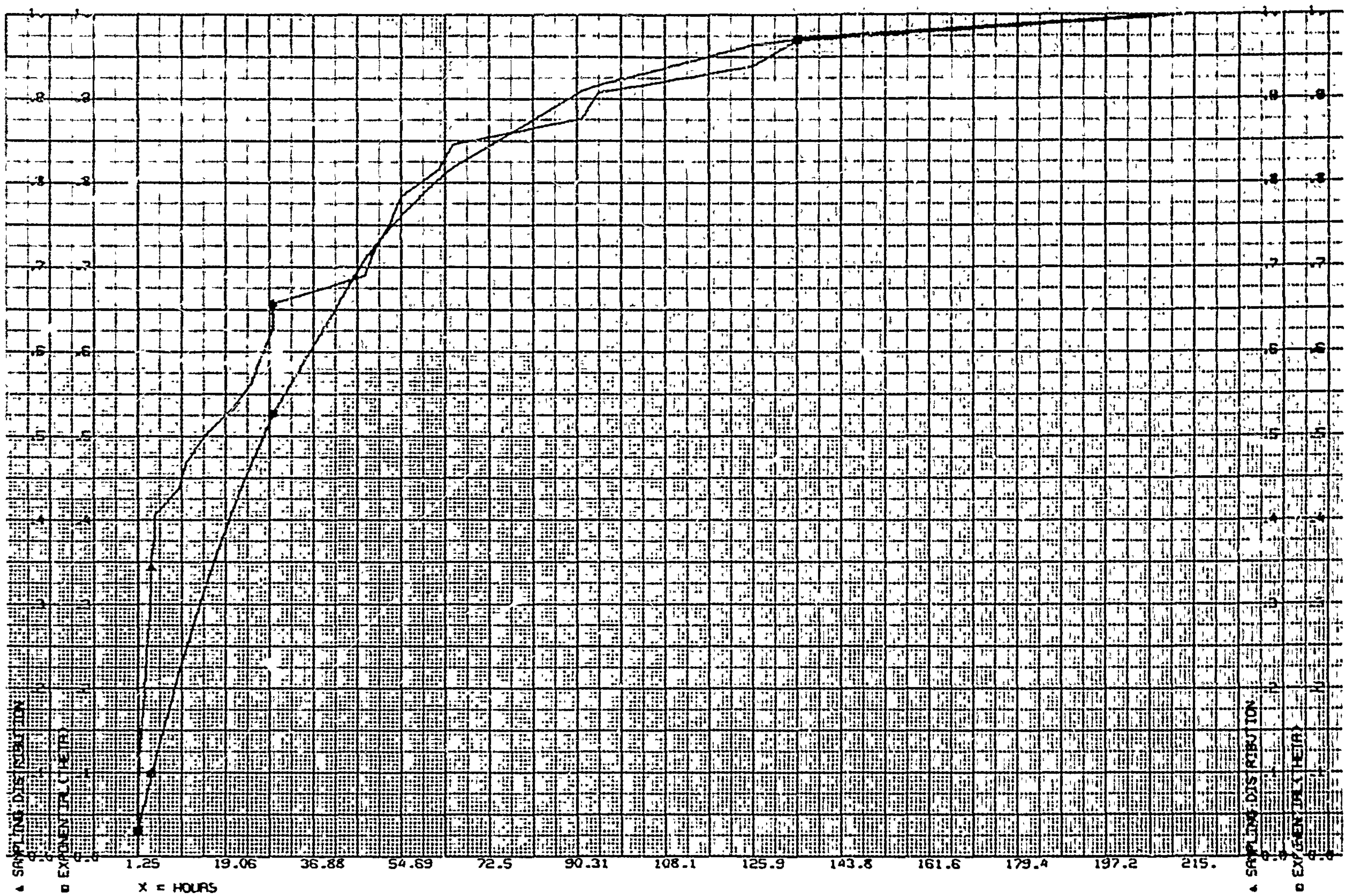

Figure 32. Test for Exponential Data: Critical LRU - Modulator, Receiver/Transmitter, Line Elapsed Hours WUC 73BDO

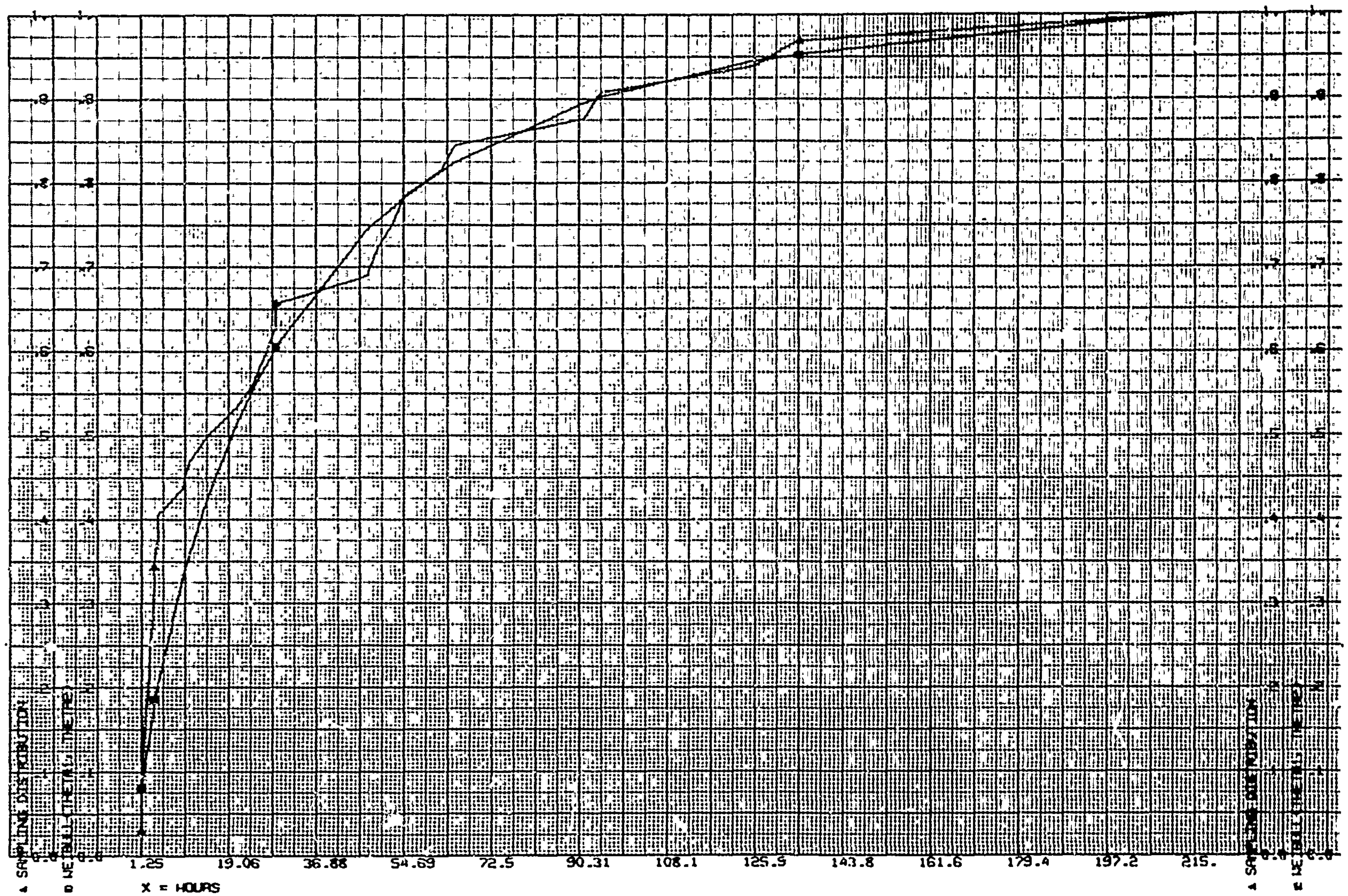

Figure 33. Test for Weibull Data: Critical LRU - Modulator, Receiver/Transmitter, Line Elapsed Hours WUC 73BDO

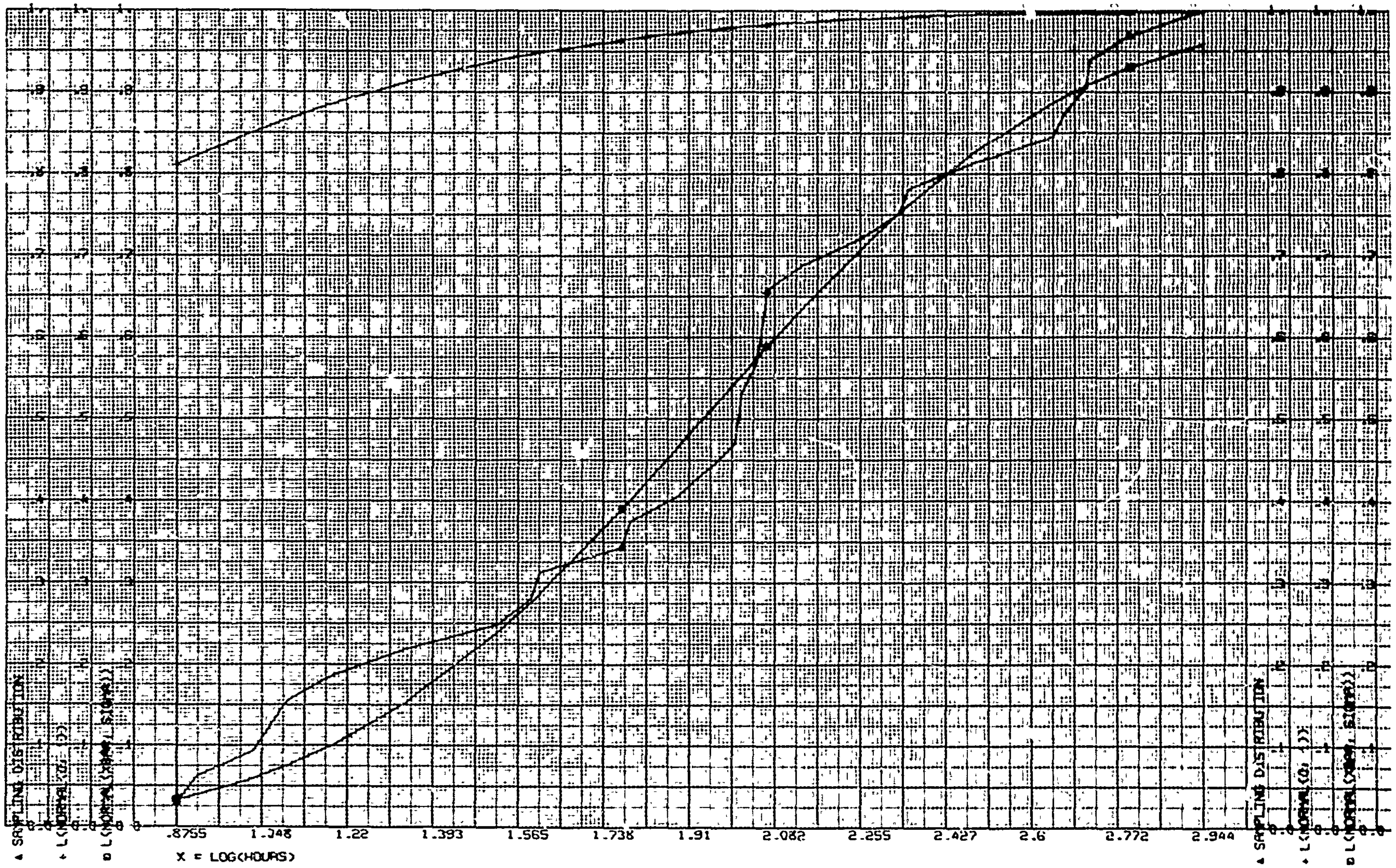

Figure 34. Test for Log Normality: Critical LRU - Modulator, Receiver/Transmitter, Line Man Hours WUC 73BDO

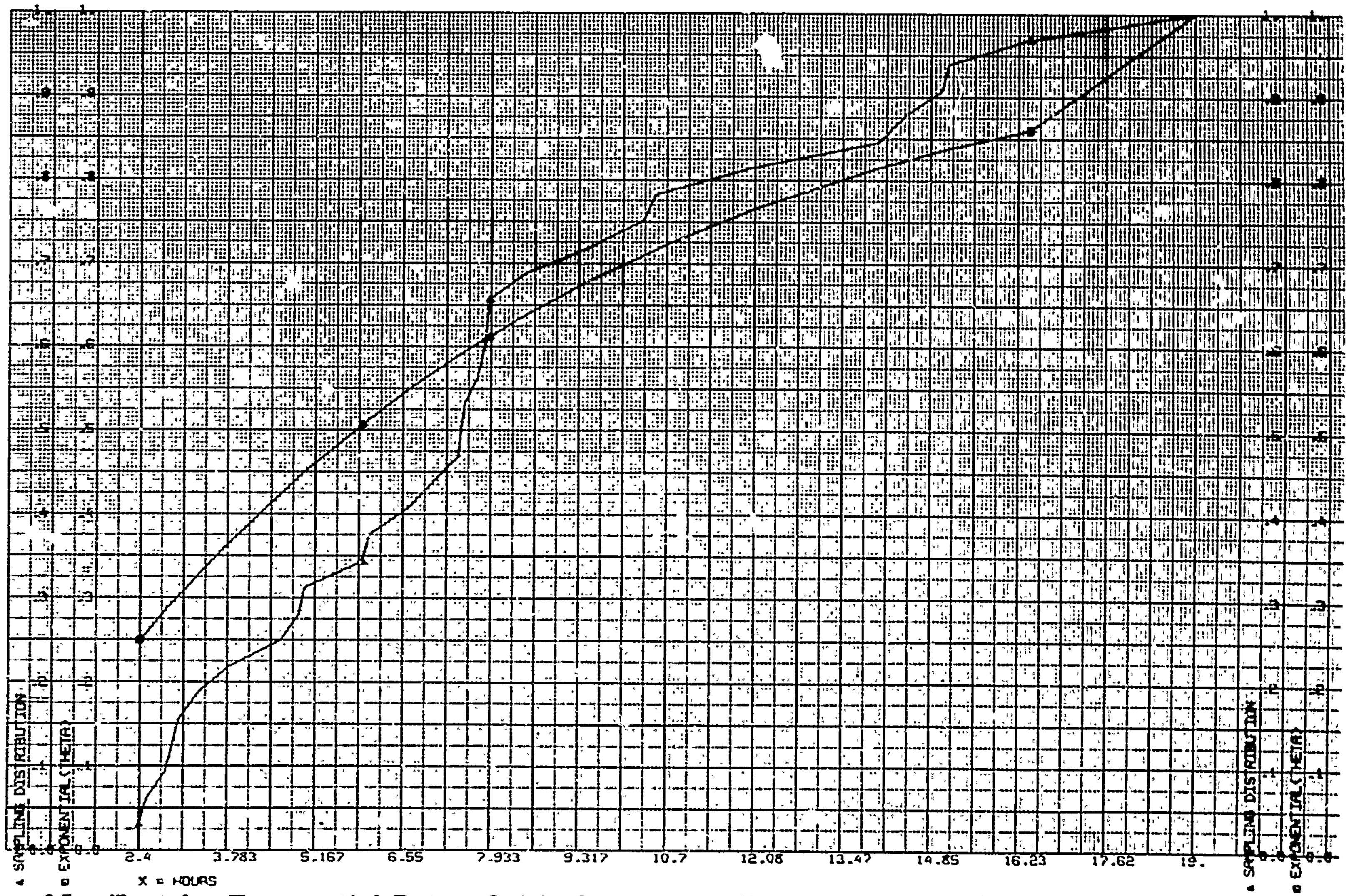

Figure 35. Test for Exponential Data: Critical LRU - Modulator, Receiver/Transmitter, Line Man Hours WUC 73BDO

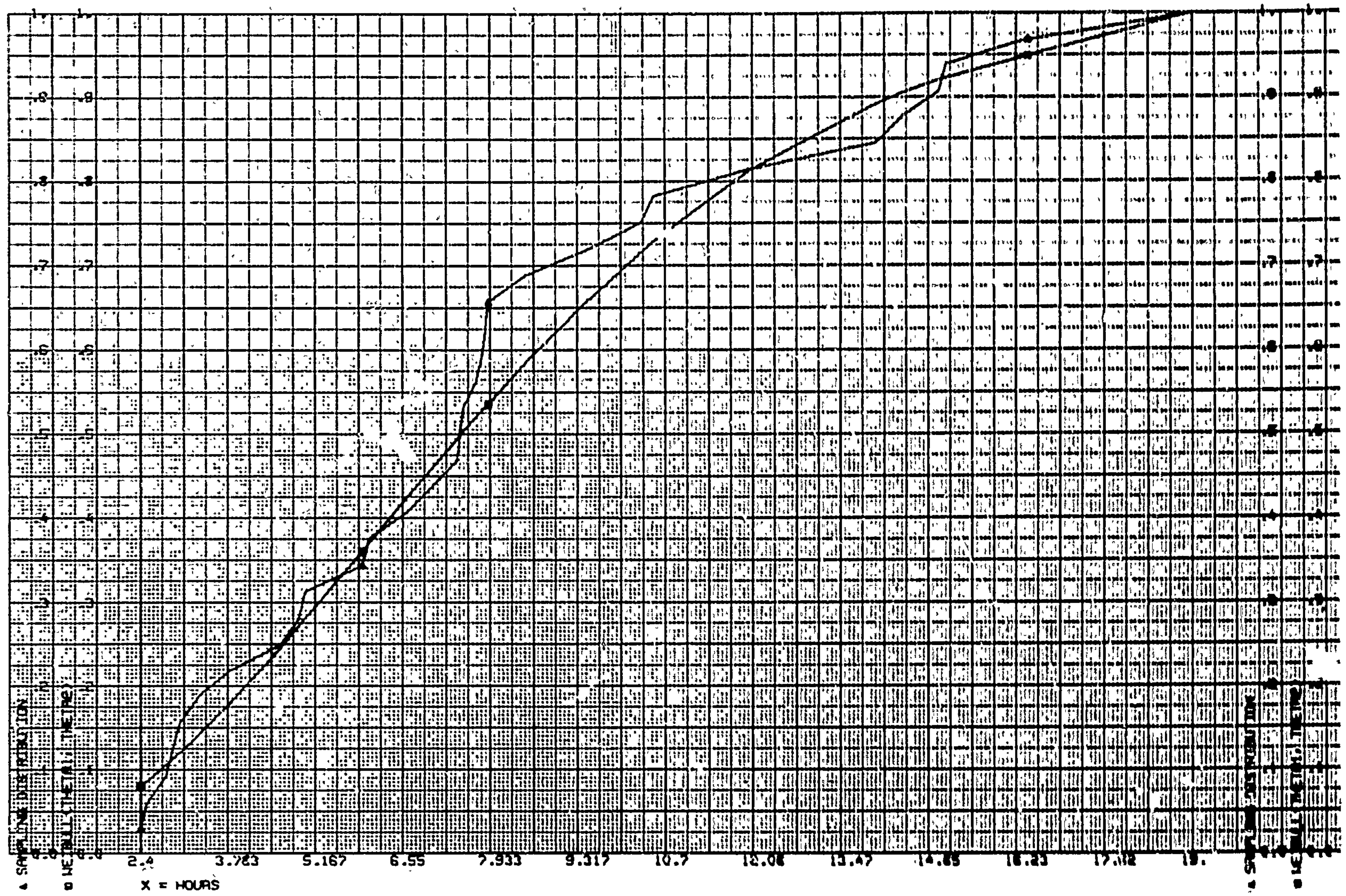

Figure 36. Test for Weibull Data: Critical LRU - Modulator, Receiver/Transmitter, Line Man Hours WUC 73BDO

Table 5: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}$: $S_n(t) \equiv F(t\|\theta)$	Sample Size	$\bar{t}$	s_t	Graph	D_n	$1-Q(D_n\sqrt{n})$	Decision
Stabilization Platform unit WUC 73AAO Shop Active Hours	L(N(0,1))	36	-	-	37	0.7044	0.0000	Reject
	L(N(2.04, 0.90))	36	-	-	37	0.1284	0.5927	
	E(0.0871)	36	11.17	9.73	38	0.1184	0.6938	
	W(1.1430, 0.0601)	36	11.17	9.73	39	0.0905	0.9294	
Shop Elapsed Hours	L(N(0,1)	36	-	-	40	0.7322	0.0000	Reject
	L(N(3.125, 4.42))	36	-	-	40	0.1667	0.2699	
	E(0.0060)	36	16.33	326.15	41	0.5029	0.0000	Reject
	W(0.5430, 0.0848)	36	16.33	326.15	42	0.2665	0.0120	Reject
Shop Man Hours	L(N(0.1))	36	-	-	43	0.8165	0.0000	Reject
	L(N(2.68, 1.23))	36	-	-	43	0.1173	0.7053	
	E(0.0417)	36	23.29	21.64	44	0.0715	0.9928	
	W(1.0710, 0.0334)	35	23.29	21.64	45	0.0678	0.9964	

Source: 258 Data System for F-111, Edwards AFB, California

See footnote Table 1 for definition of $L(N(\mu,\sigma^2))$, $E(\lambda)$ and $W(\theta,\lambda)$.

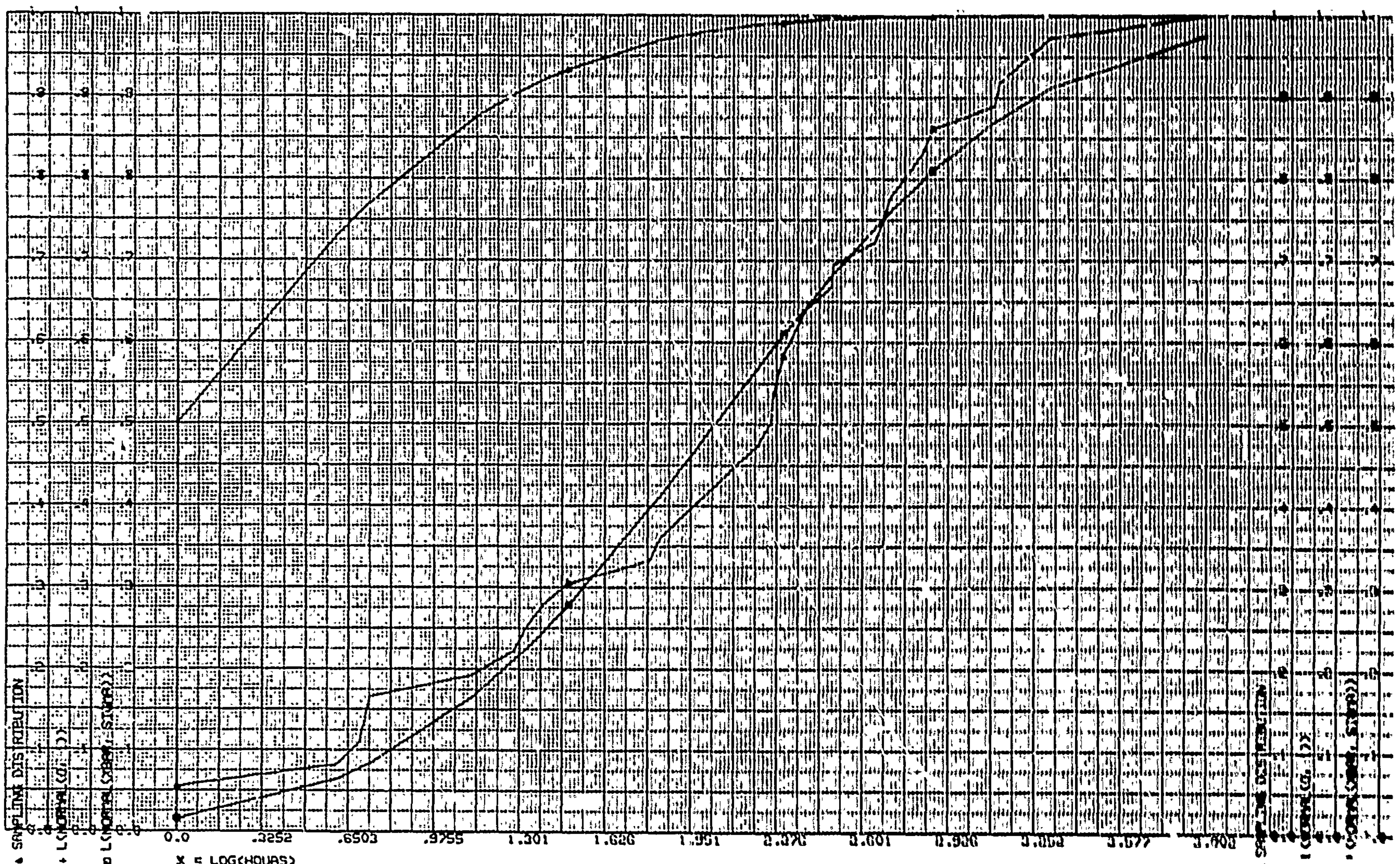

Figure 37. Test for Log Normality: Critical LRU - Stabilization Platform Unit, Shop Active Hours WUC 73AAO

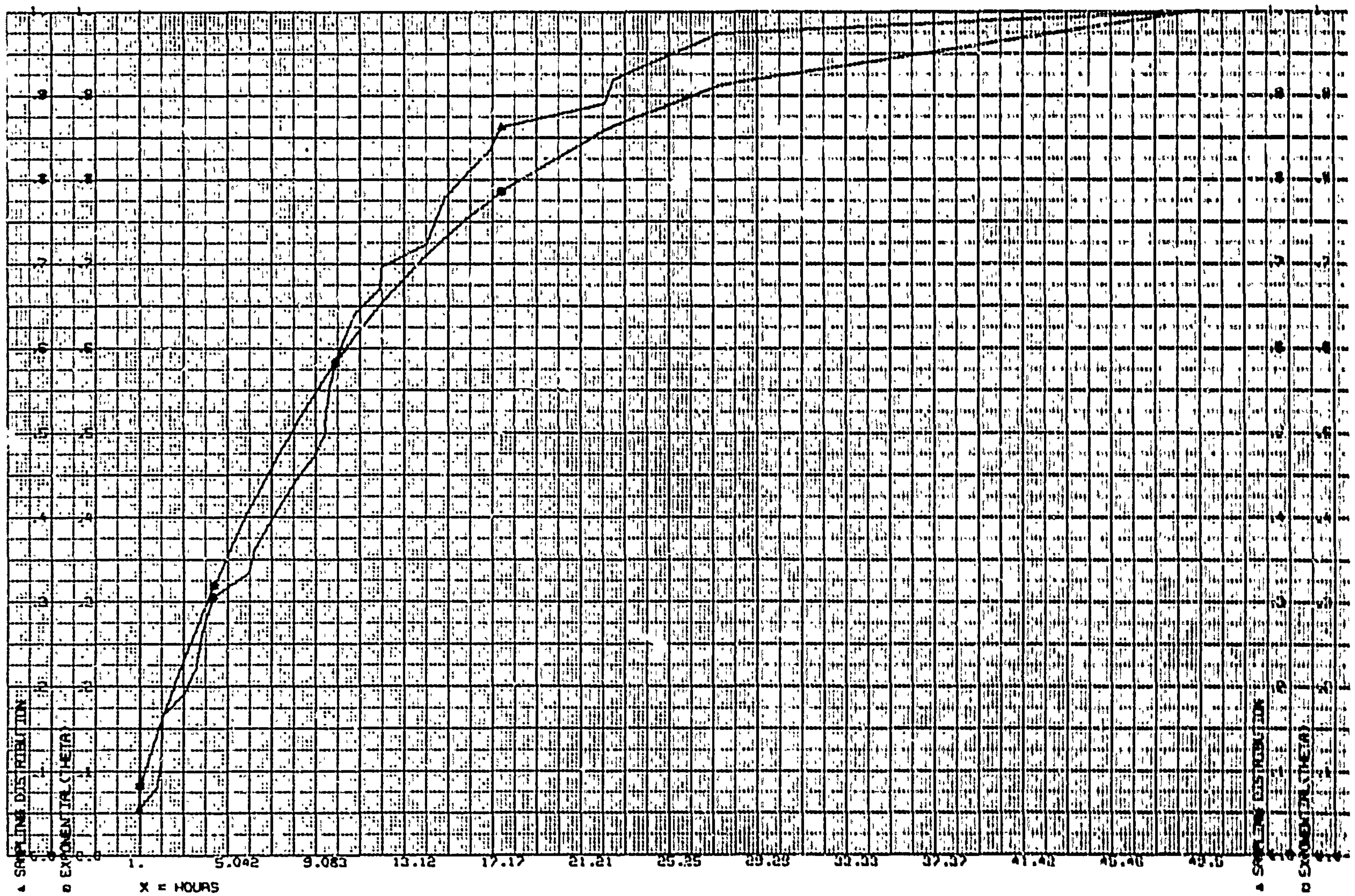

Figure 38. Test for Exponential Data: Critical LRU - Stabilization Platform Unit, Shop Active Hours WUC 73AAO

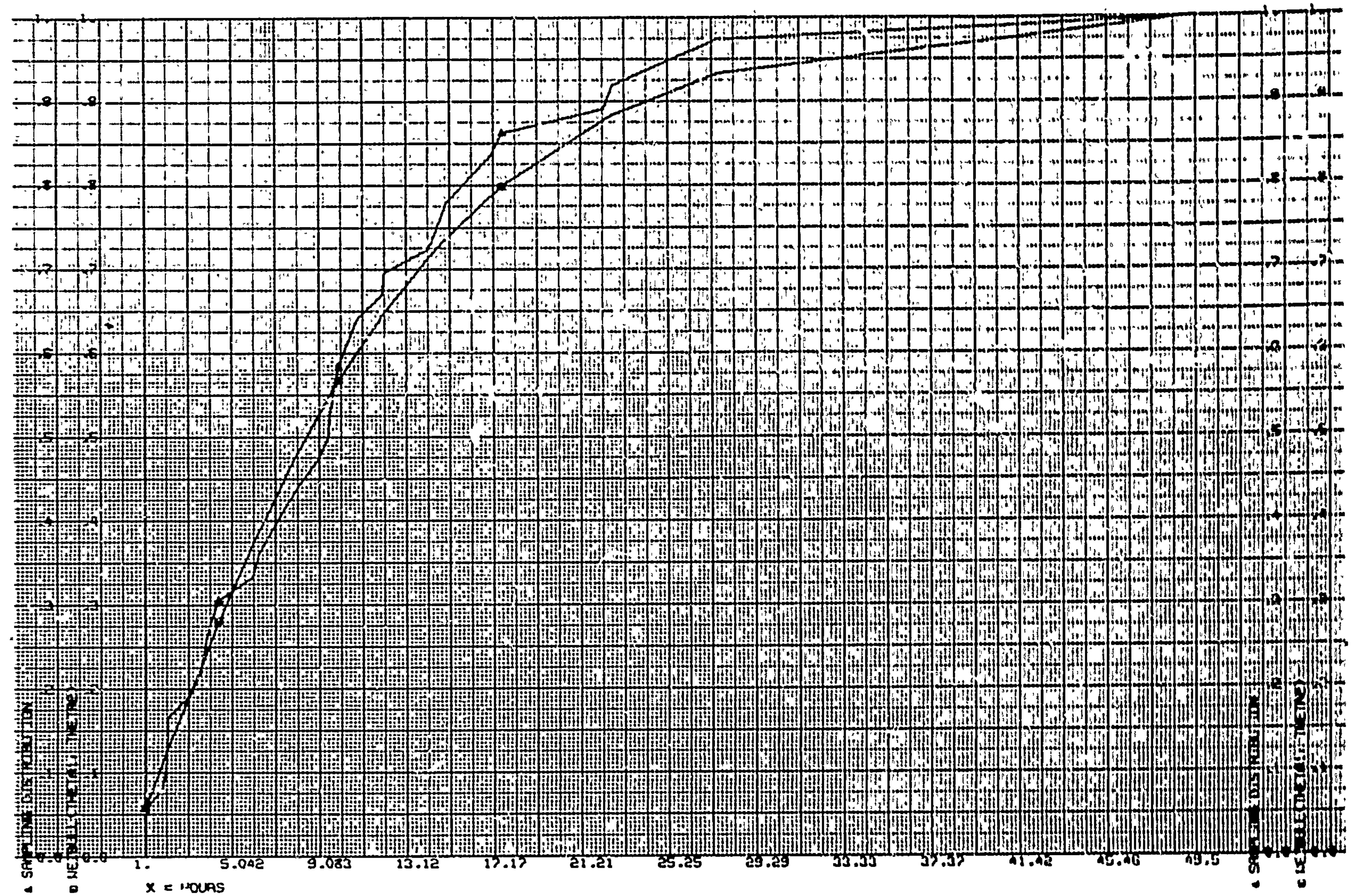

Figure 39. Test for Weibull Data: Critical LRU - Stabilization Platform Unit, Shop Active Hours WUC 73AAO

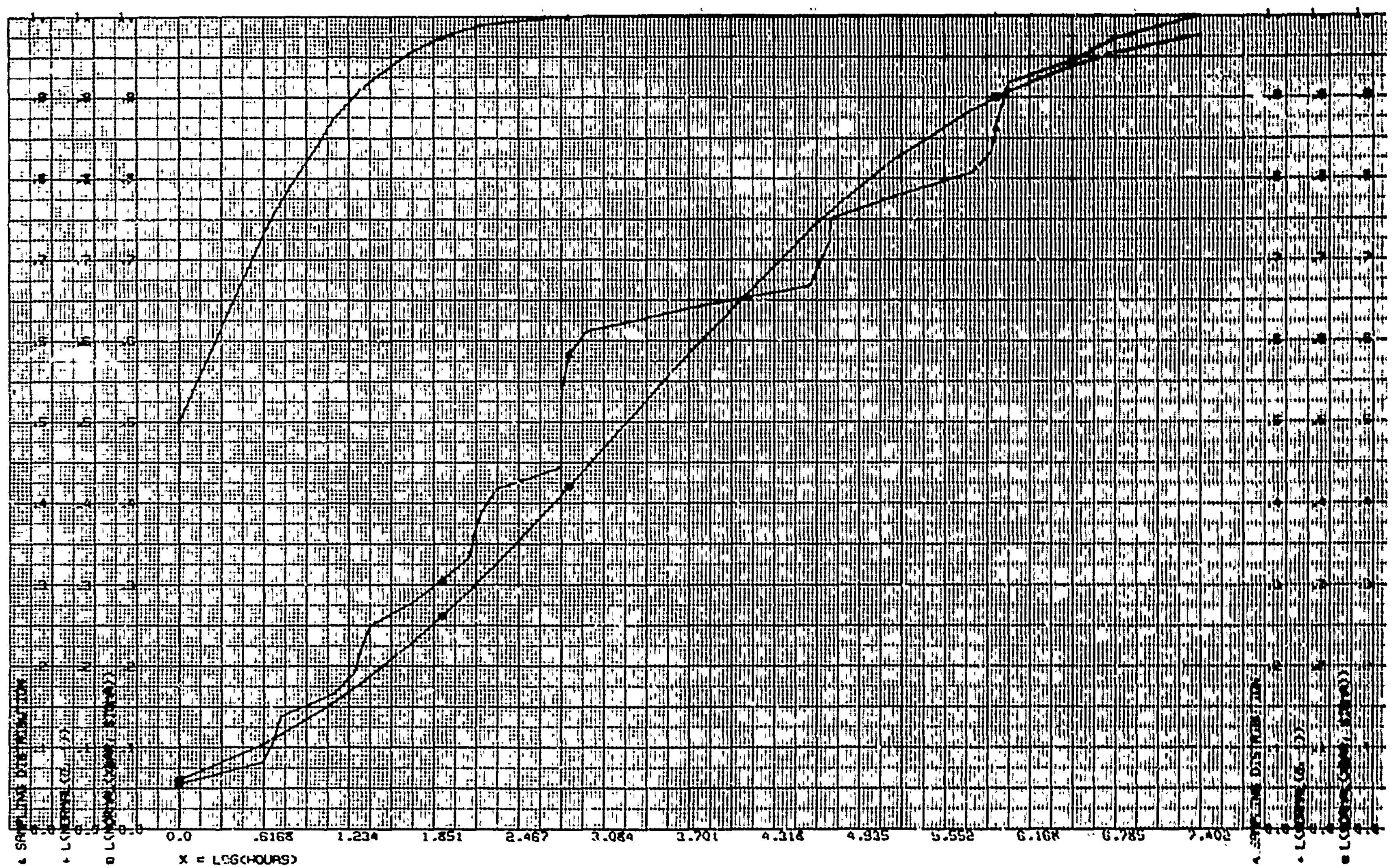

Figure 40. Test for Log Normality: Critical LRU - Stabilization Platform Unit, Shop Elapsed Hours WUC 73AAO

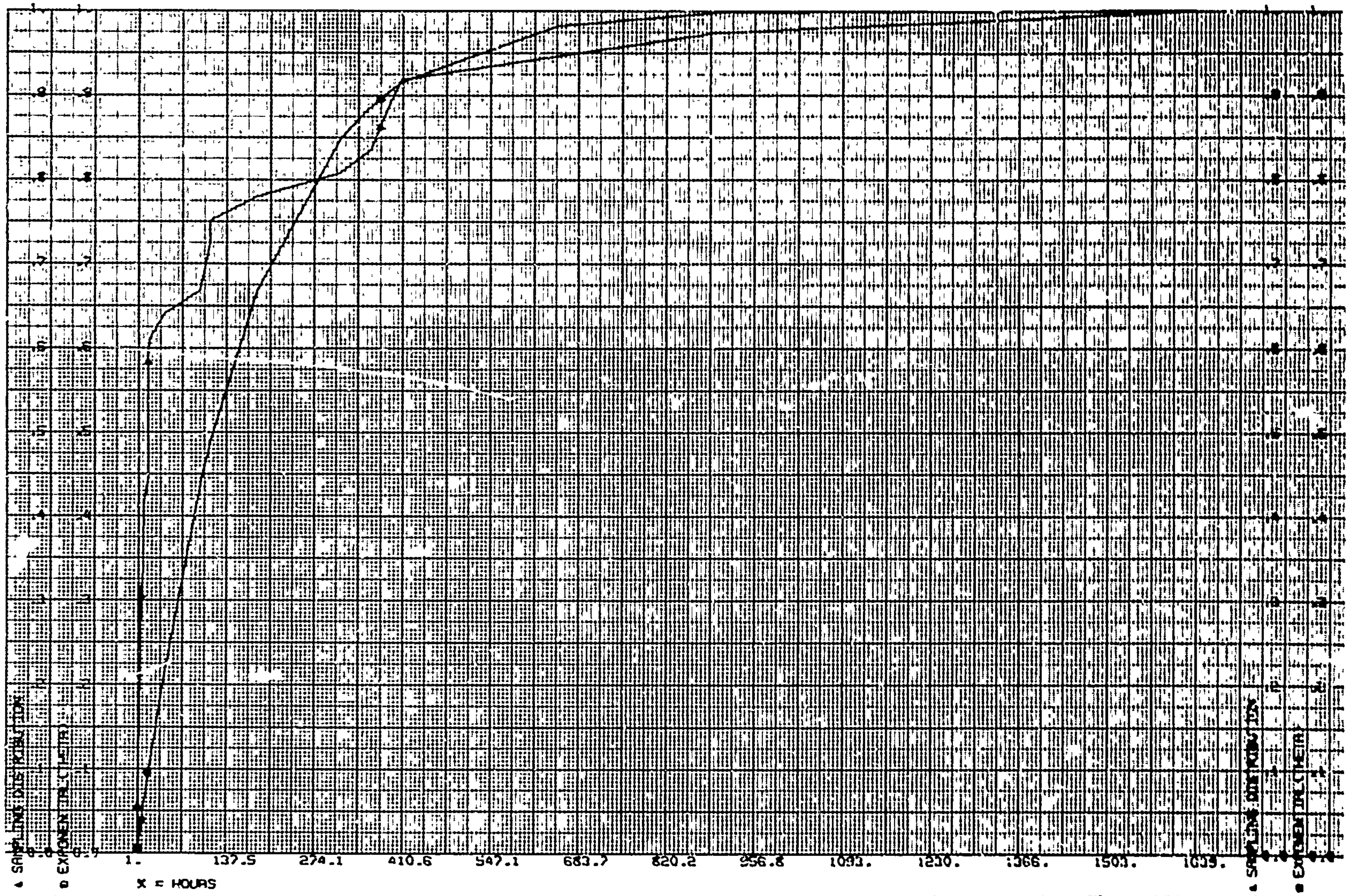

Figure 41. Test for Exponential Data: Critical LRU - Stabilization Platform Unit, Shop Elapsed Hours WUC 73AAO

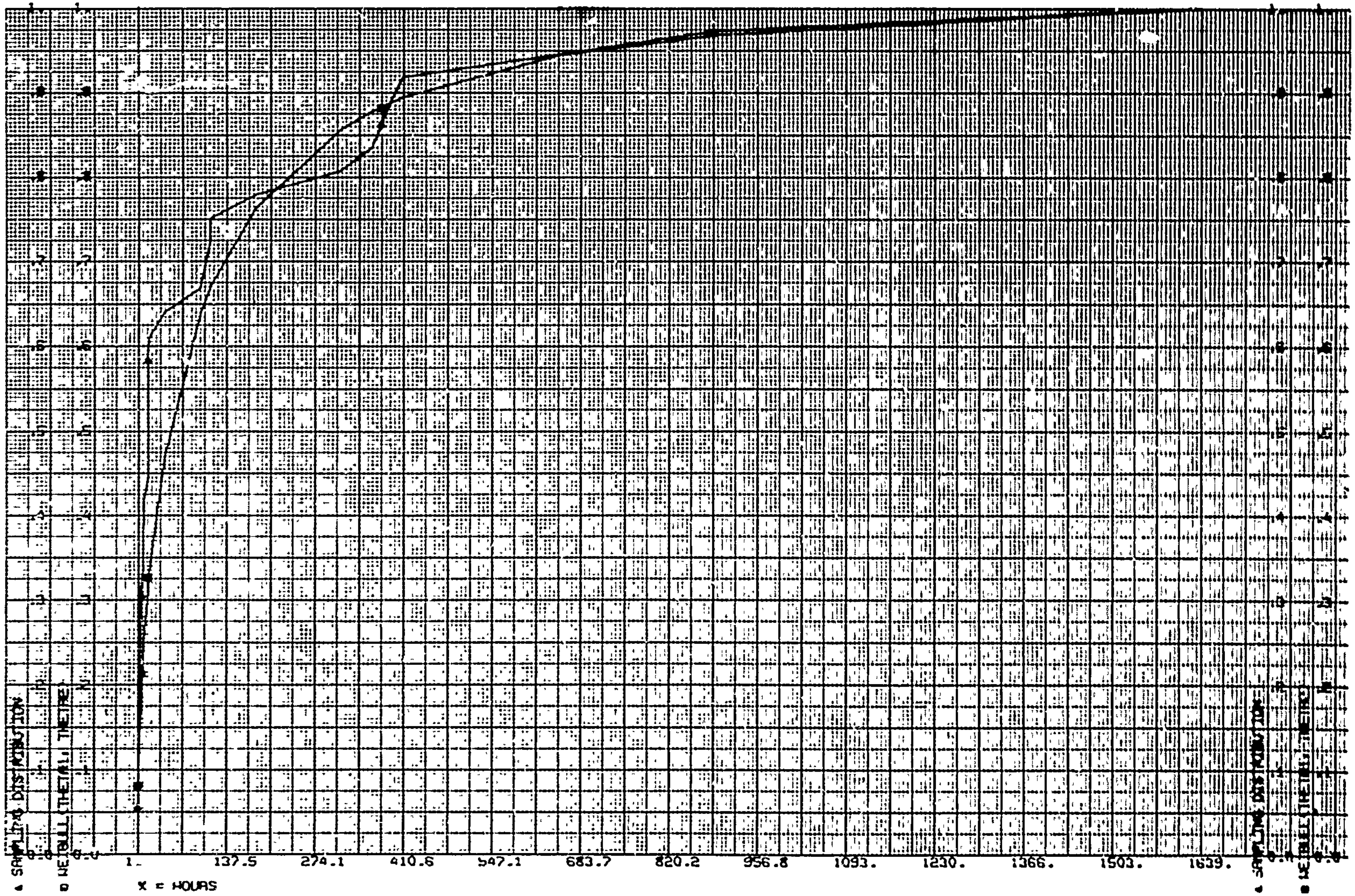

Figure 42. Test for Weibull Data: Critical LRU - Stabilization Platform Unit, Shop Elapsed Hours WUC 73AAO

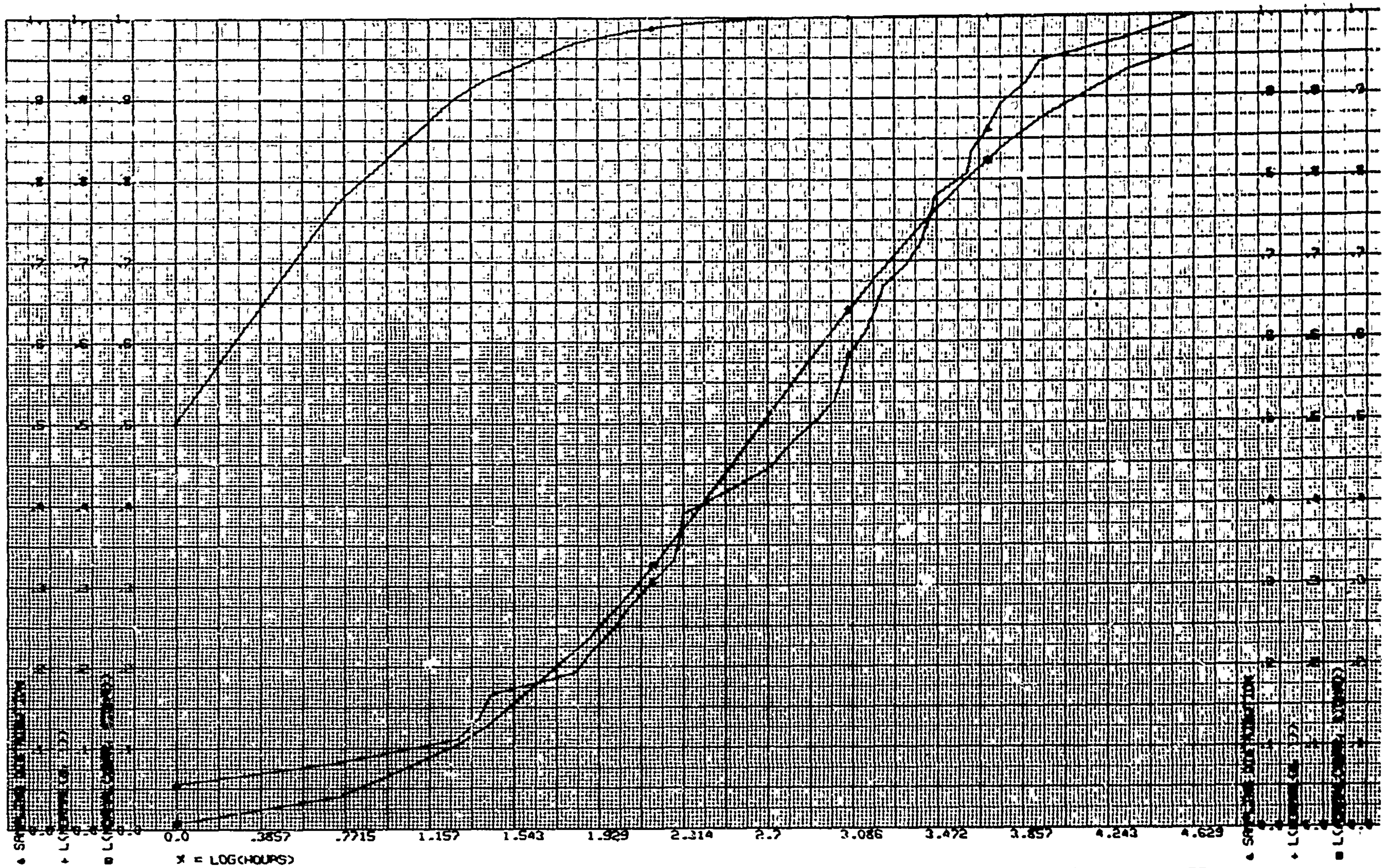

Figure 43. Test for Log Normality: Critical LRU - Stabilization Platform Unit, Shop Man Hours WUC 73AAO

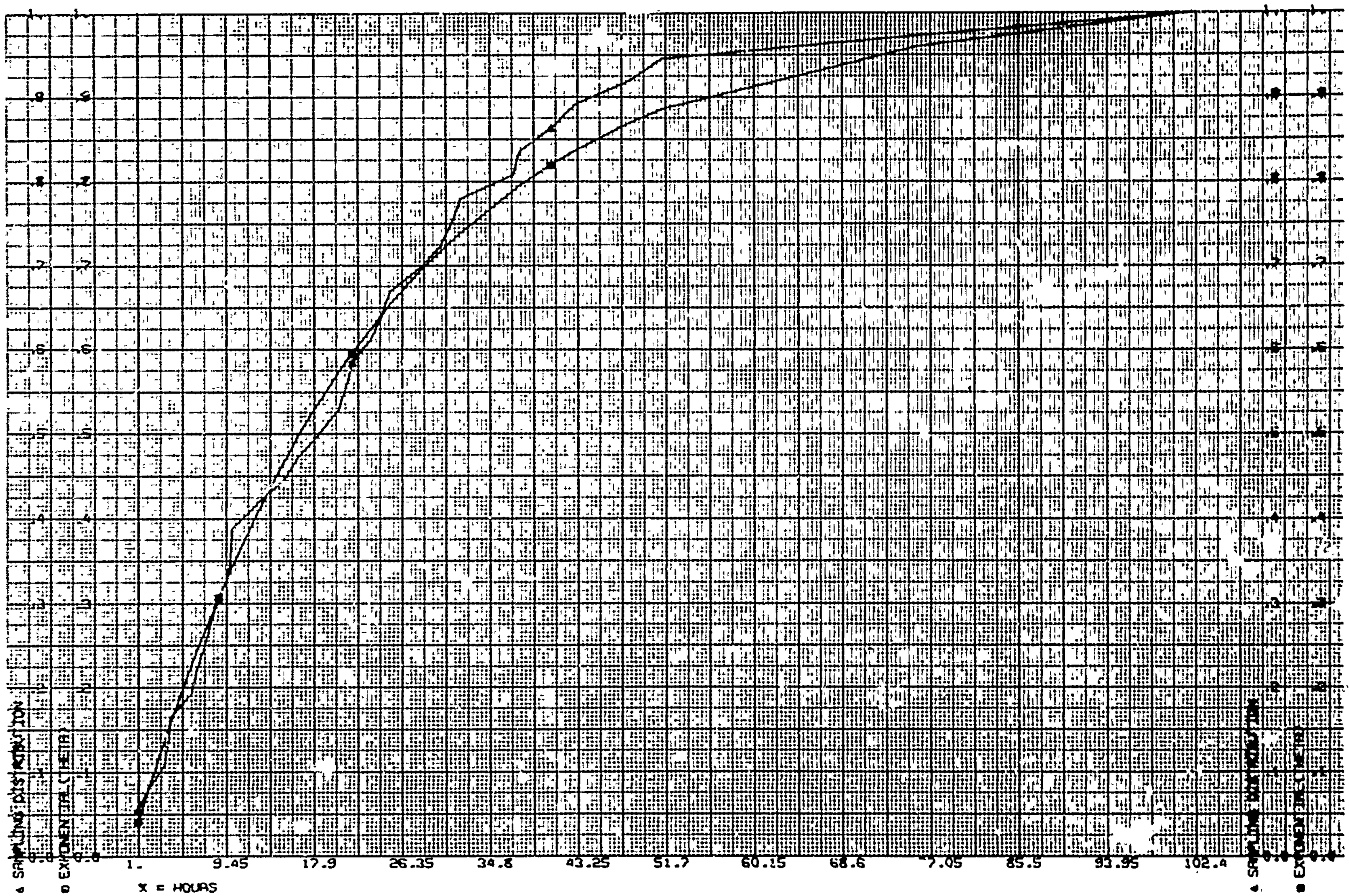

Figure 44. Test for Exponential Data: Critical LRU - Stabilization Platform Unit, Shop Man Hours WUC 73AAO

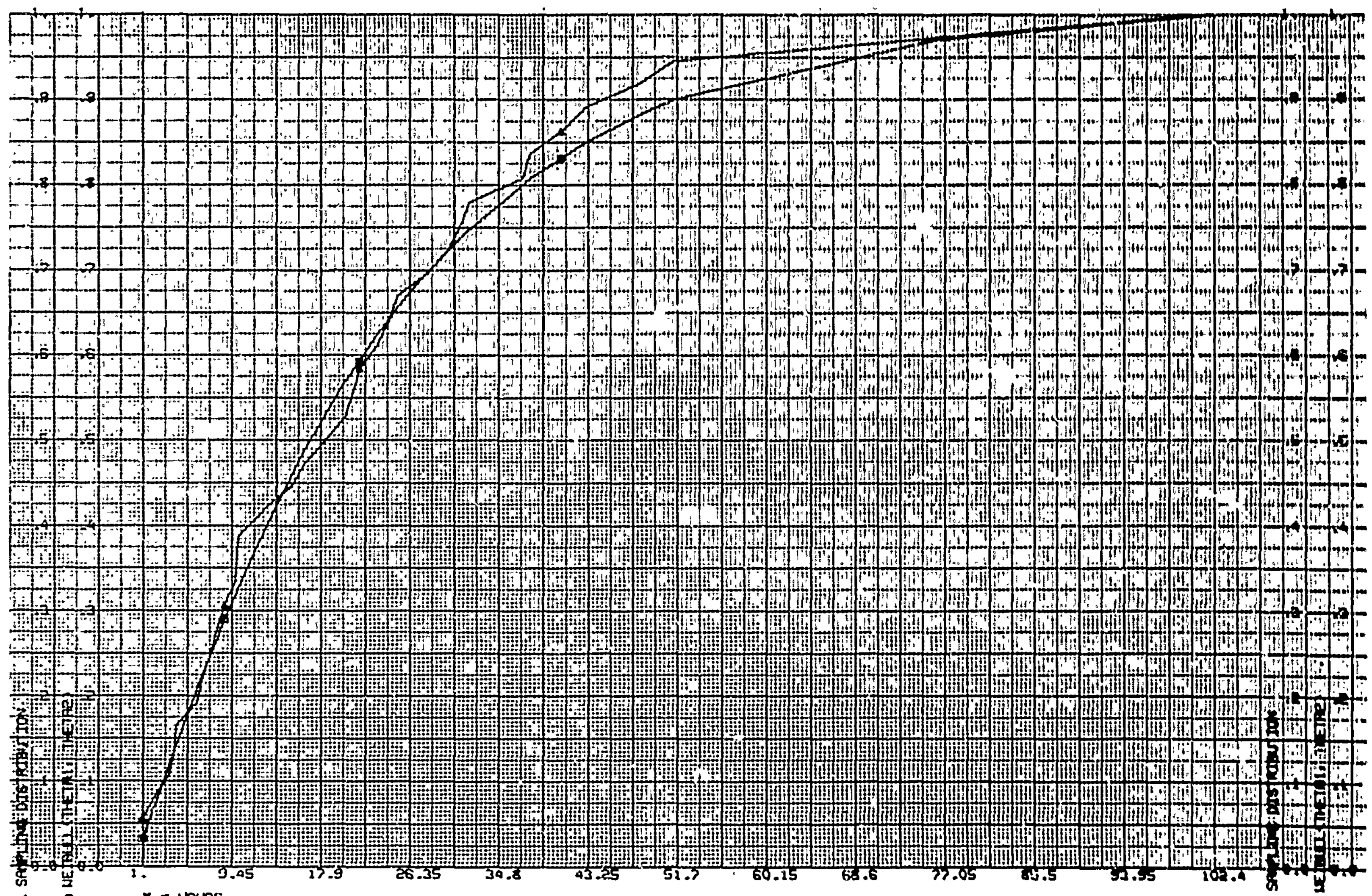

Figure 45. Test for Weibull Data: Critical LRU - Stabilization Platform Unit, Shop Man Hours WUC 73AAO

Table 6: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}: S_n(t) \equiv F(t\|\theta)$	Sample Size	$\bar{t}$	s_t	Graph	D_n	$1 - Q(D_n\sqrt{n})$	Decision
Stabilization Platform unit WUC 73AAO Line Active Hours	L(N(0,1))	32	-	-	46	0.6557	0.0000	Reject
	L(N(1.44, 0.67))	32	-	-	46	0.0914	0.9521	
	E(0.1737)	32	5.57	4.33	47	0.1997	0.1558	
	W(1.2880, 0.0989)	32	5.57	4.33	48	0.1224	0.7241	
Line Elapsed Hours	L(N(0,1))	32	-	-	49	0.7819	0.0000	Reject
	L(N(2.74, 2.54))	32	-	-	49	0.0964	0.9274	
	E(0.0237)	32	40.87	52.15	50	0.2180	0.0955	
	W(0.7890, 0.0595)	32	40.87	52.15	51	0.1350	0.6038	
Line Man Hours	L(N(0,1))	32	-	-	52	0.8327	0.0000	Reject
	L(N(2.13, 0.09))	32	-	-	52	0.1302	0.6500	
	E(0.0846)	32	11.45	8.38	53	0.1929	0.1848	
	W(1.3700, 0.0313)	32	11.45	8.38	54	0.1004	0.9034	

Source: 258 Data System for the F-111, Edwards AFB, California

See Table 1 for definition of $L(N(\mu, \sigma^2))$, $E(\lambda)$ and $W(\theta,\lambda)$.

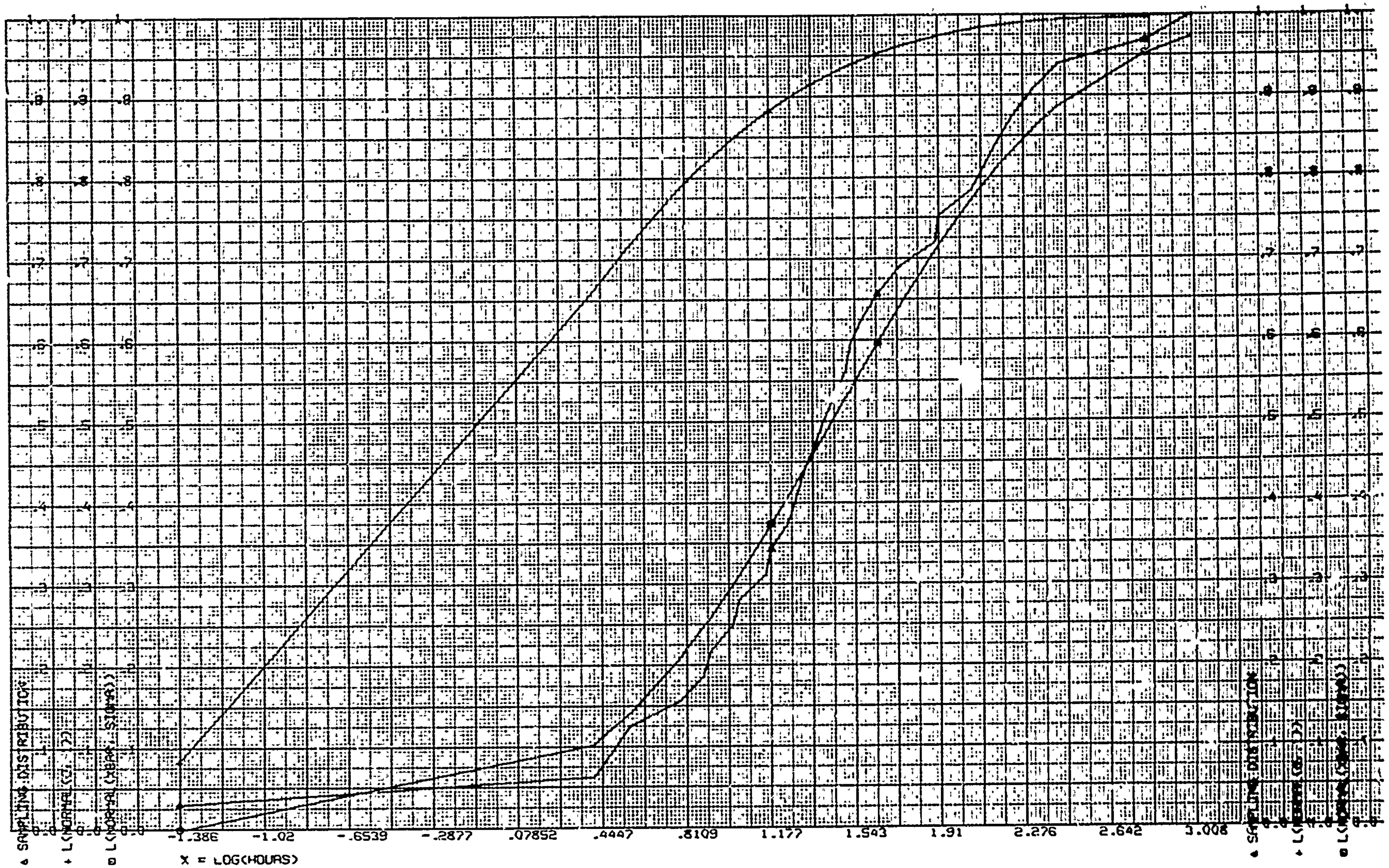

Figure 46. Test for Log Normality: Critical LRU - Stabilization Platform Unit, Line Active Hours WUC 73AAO

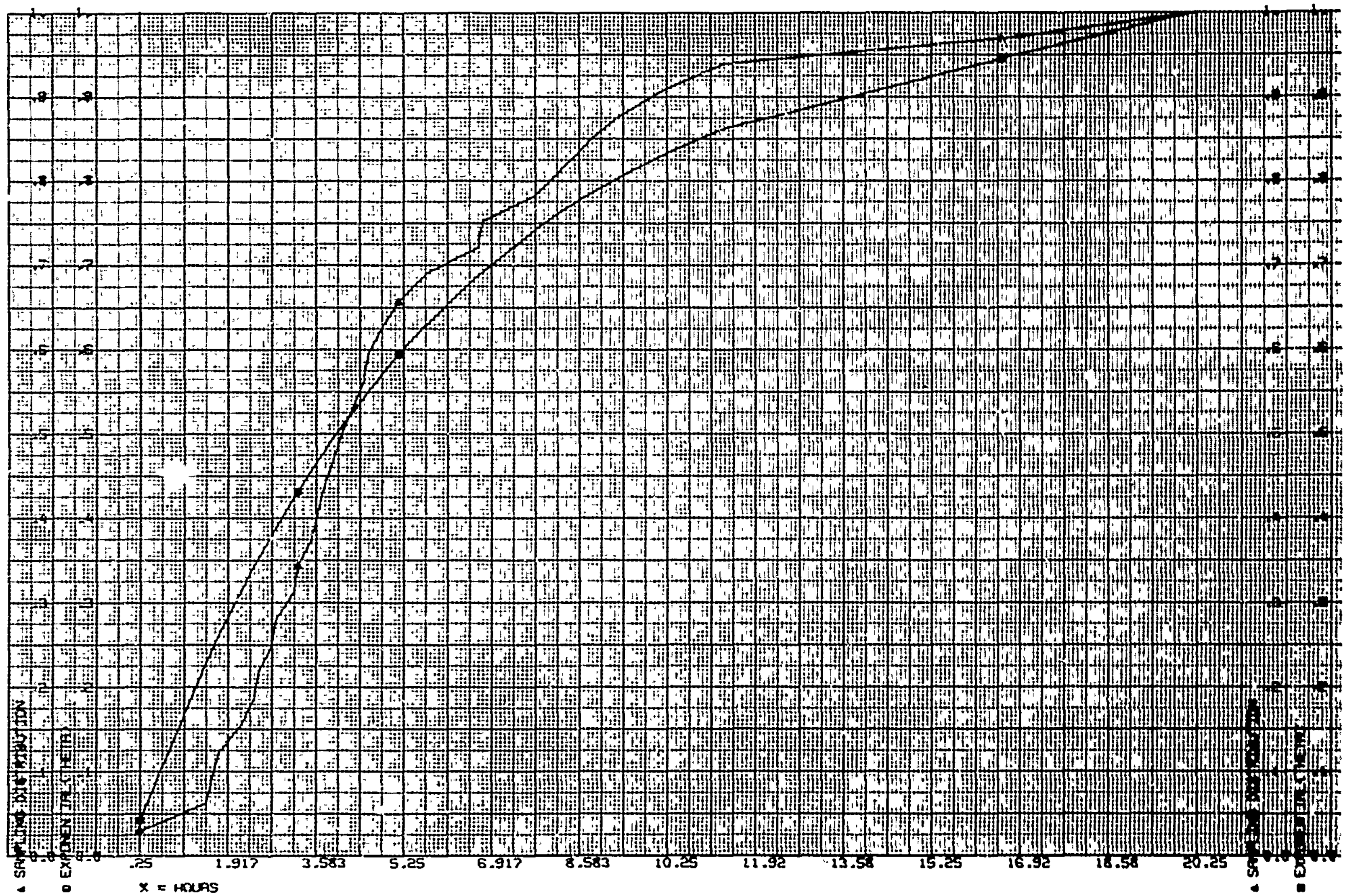

Figure 47. Test for Exponential Data: Critical LRU - Stabilization Platform Unit, Line Active Hours WUC 73AAO

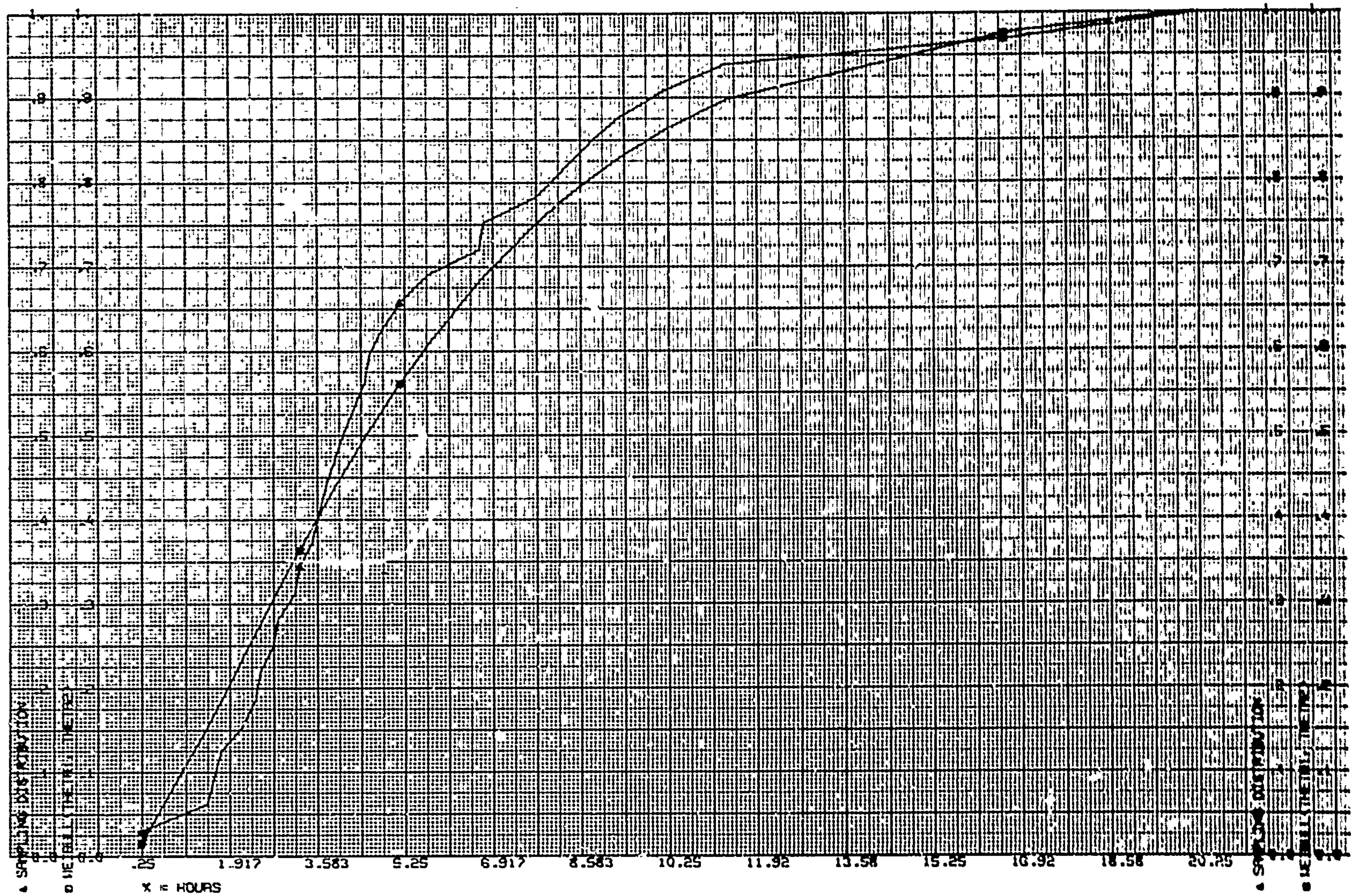

Figure 48. Test for Weibull Data: Critical LRU - Stabilization Platform Unit, Line Active Hours WUC 73AAO

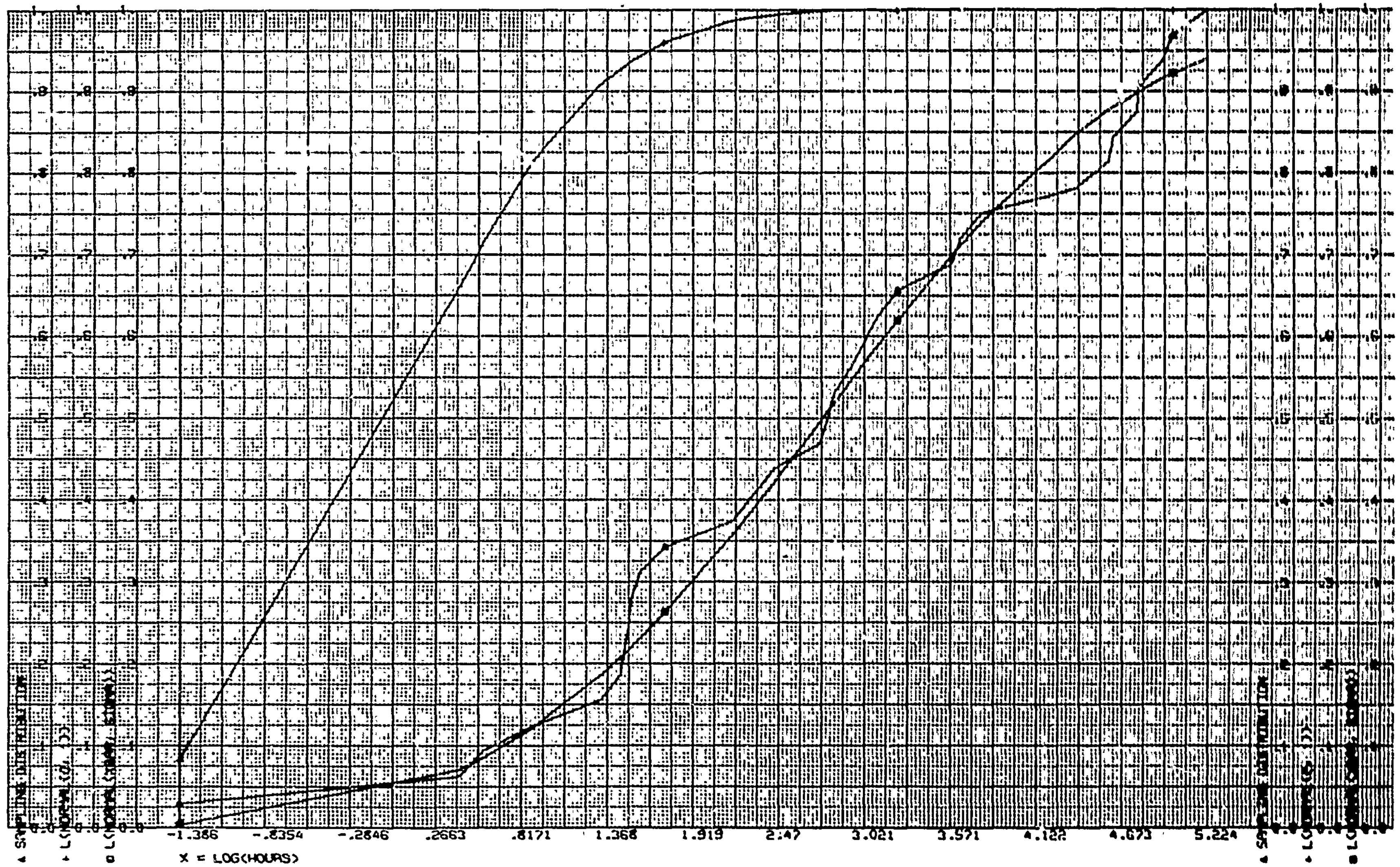

Figure 49. Test for Log Normality: Critical LRU - Stabilization Platform Unit, Line Elapsed Hours WUC 73AAO

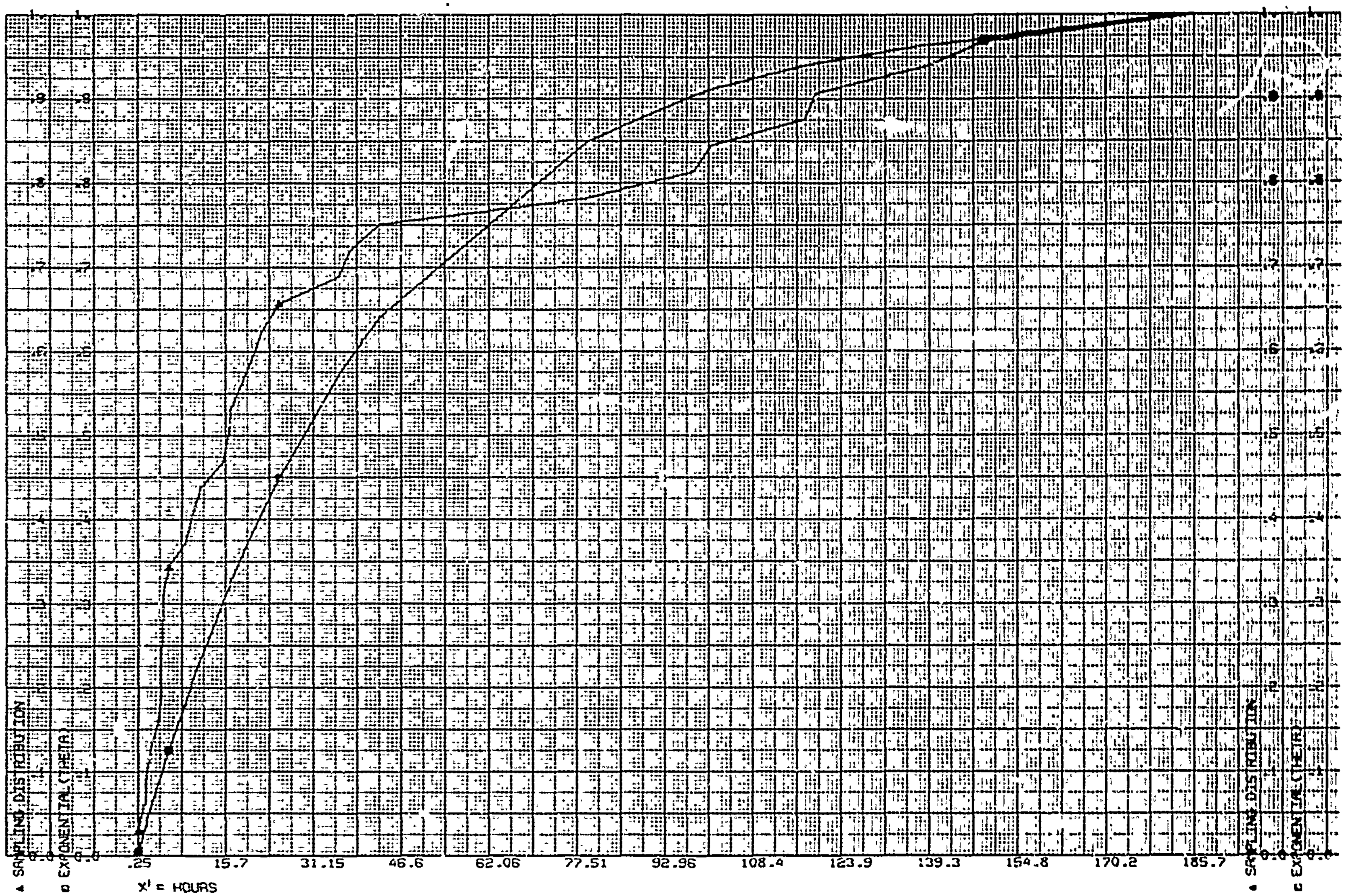

Figure 50. Test for Exponential Data: Critical LRU - Stabilization Platform Unit, Line Elapsed Hours WUC 73AAO

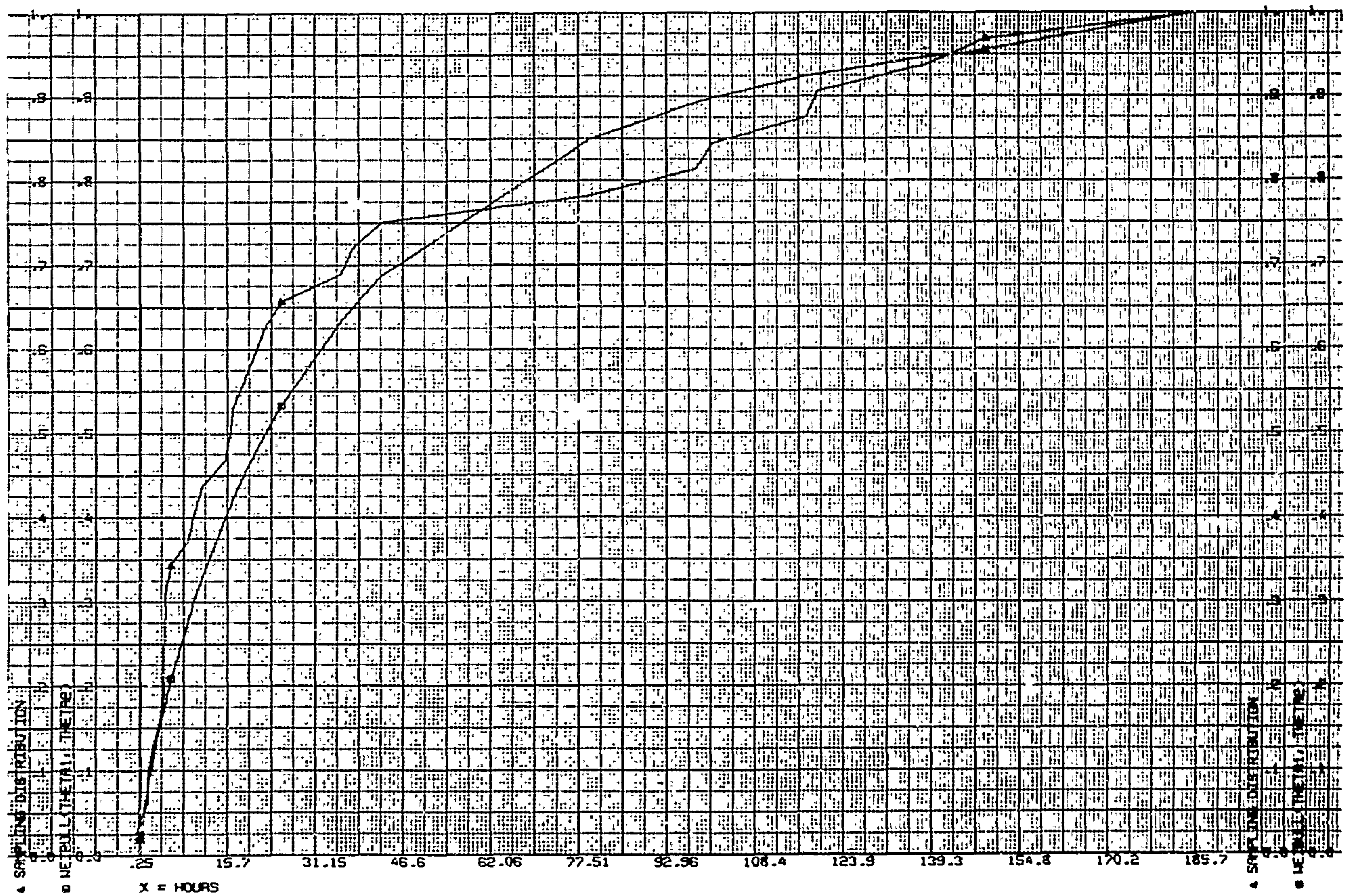

Figure 51. Test for Weibull Data: Critical LRU - Stabilization Platform Unit, Line Elapsed Hours WUC 73AAO

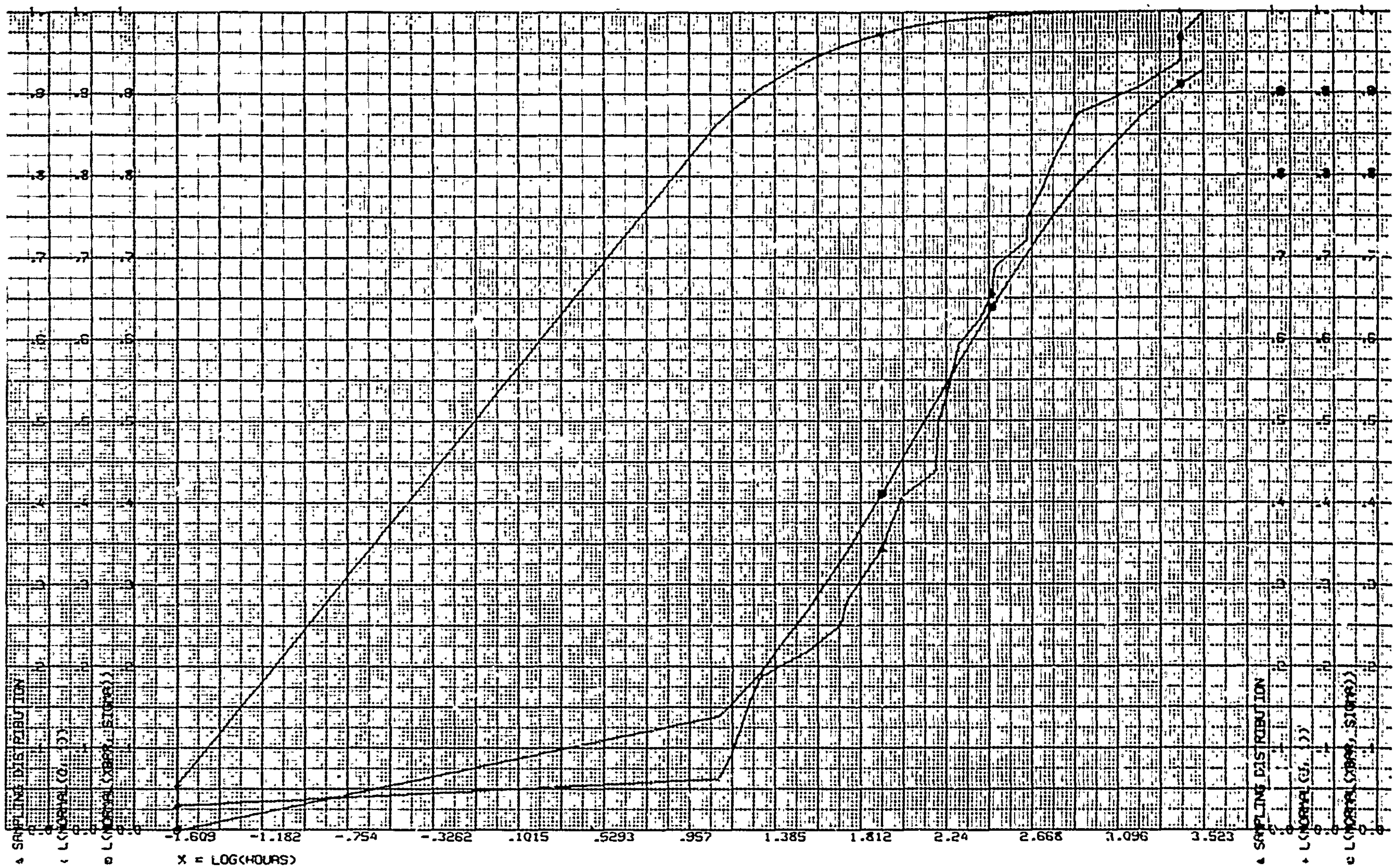

Figure 52. Tcst for Log Normality: Critical LRU - Stabilization Platform Unit, Line Man Hours WUC 73AAO

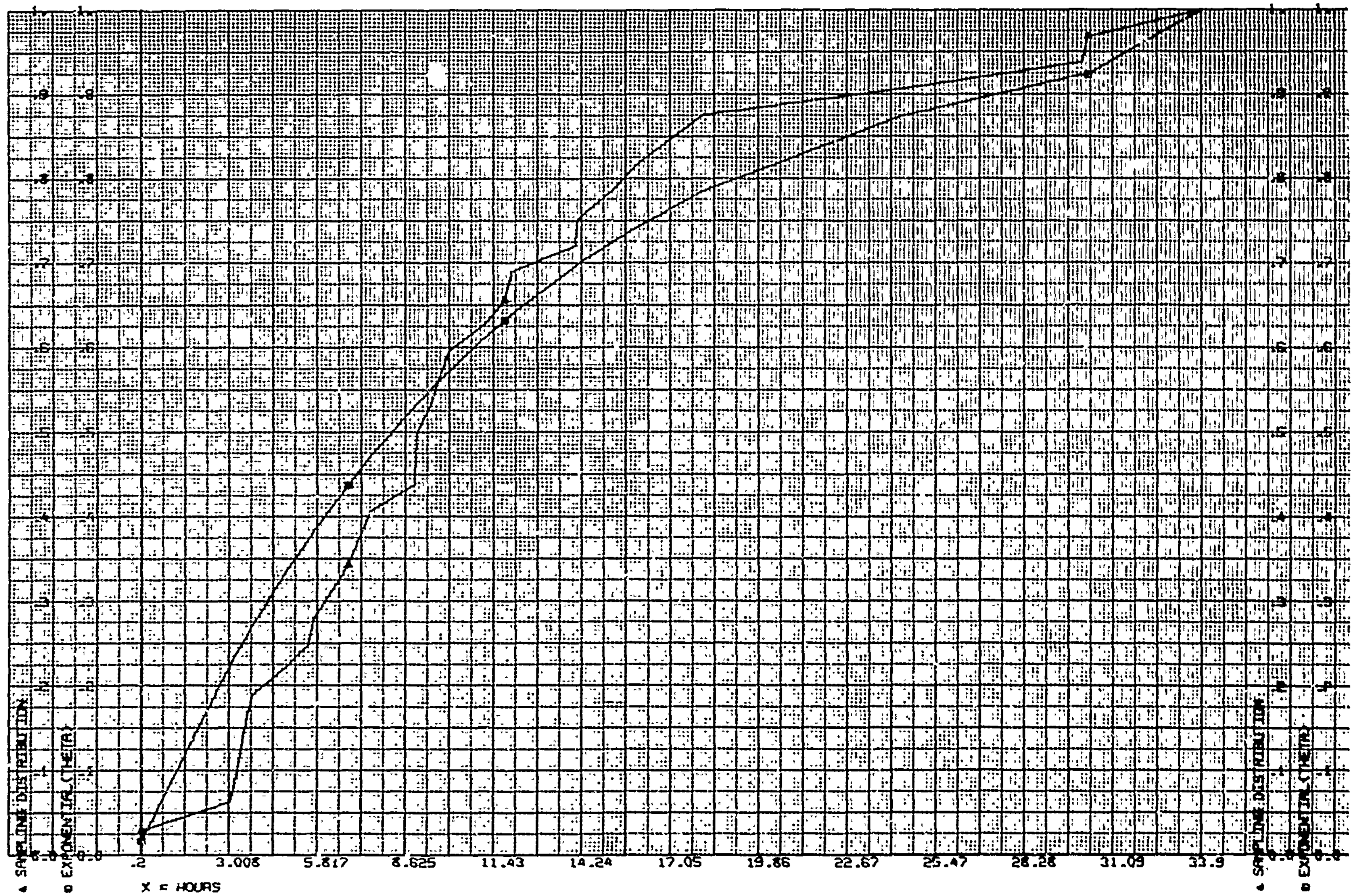

Figure 53. Test for Exponential Data: Critical LRU - Stabilization Platform Unit, Line Man Hours WUC 73AAO

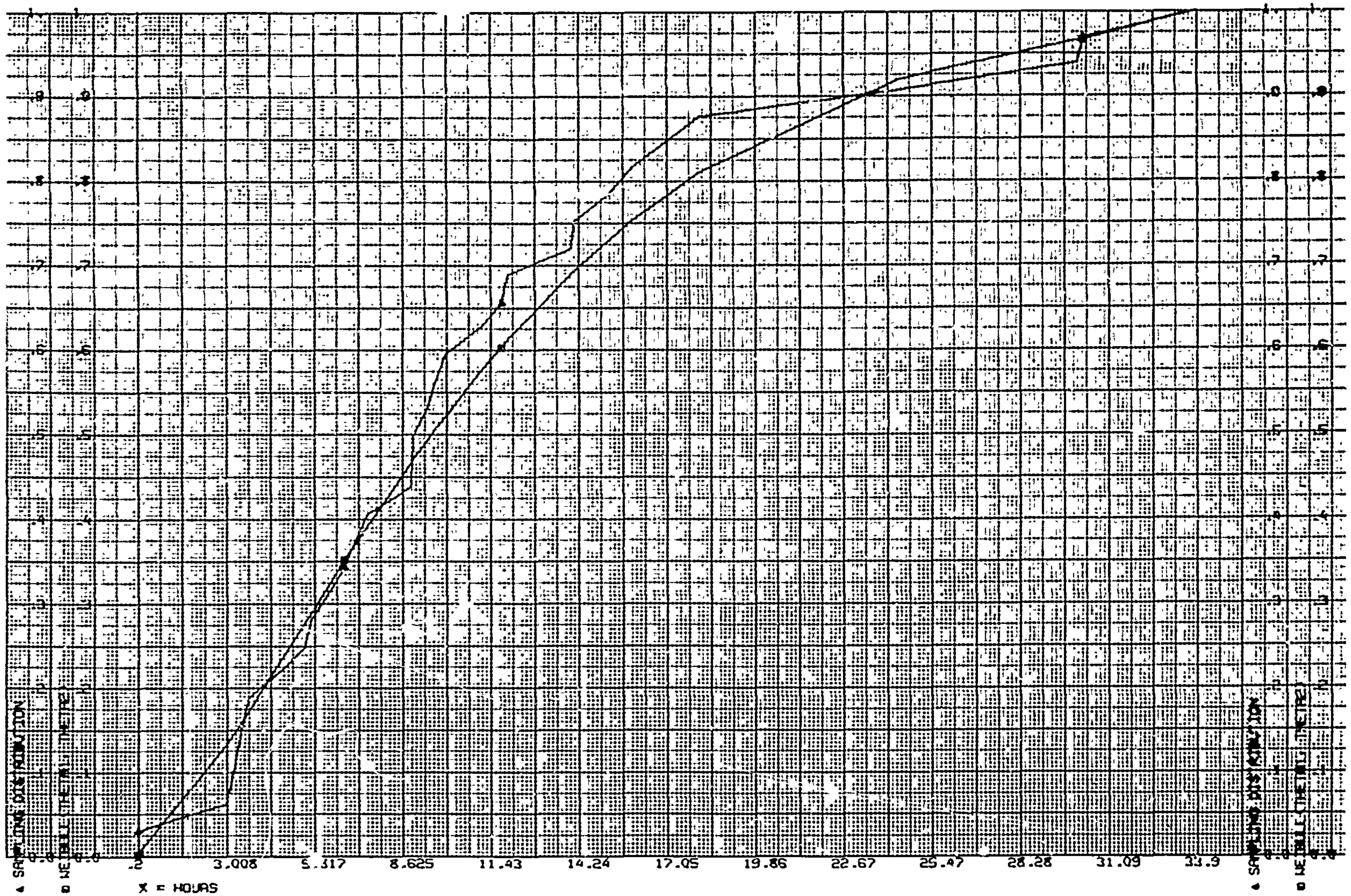

Figure 54. Test for Weibull Data: Critical LRU - Stabilization Platform Unit, Line Man Hours WUC 73AAO

Table 7: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}$: $S_n(t) \equiv F(t\|\theta)$	Sample Size	$\bar{t}$	s_t	Graph	D_n	$1 - Q(D_n\sqrt{n})$	Decision
Navigational Computer CP812/AJQ-20 WUC 73AB0 Shop Active Hours	L(N(1.52, 1.58)) E(0.1267) W(1.1600, 0.0887)	34 34 34	- 7.66 7.66	- 6.58 6.58	55 56 57	0.1310 0.0840 0.0848	0.6043 0.9701 0.9673	
Shop Elapsed Hours	L(N(1.95, 2.98)) E(0.0319) W*	34 34 34	- 30.38 30.38	- 80.65 80.65	58 59 -	0.09790 0.3876 -	0.9004 0.0000 -	Reject
Shop Man Hours	L(N(2.20, 2.01)) E(0.0595) W(1.1760, 0.0351)	34 34 34	- 16.32 16.32	- 13.84 13.84	60 61 62	0.2075 0.1507 0.1316	0.1071 0.4232 0.5976	

Source: 258 Data System for F-111, Edwards AFB, California.

See Table 1 for definition of $L(N(\mu,\sigma^2))$, $E(\lambda)$ and $W(\beta,\lambda)$.

*No fit possible.

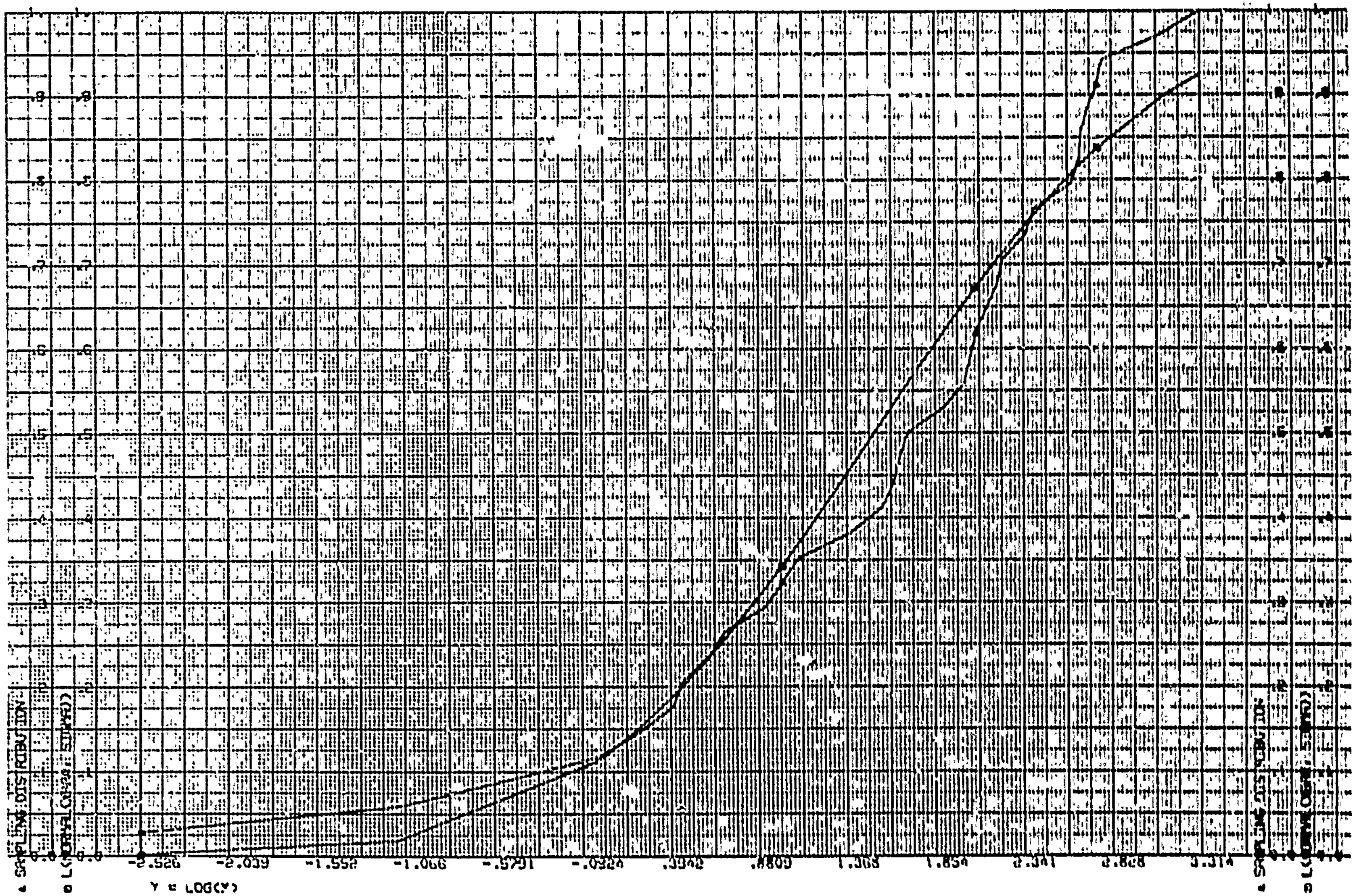

Figure 55. Test for Log Normality: Critical LRU - Navigational Computer CP812/AJQ-20 Shop Activo Hours WUC 73ABO

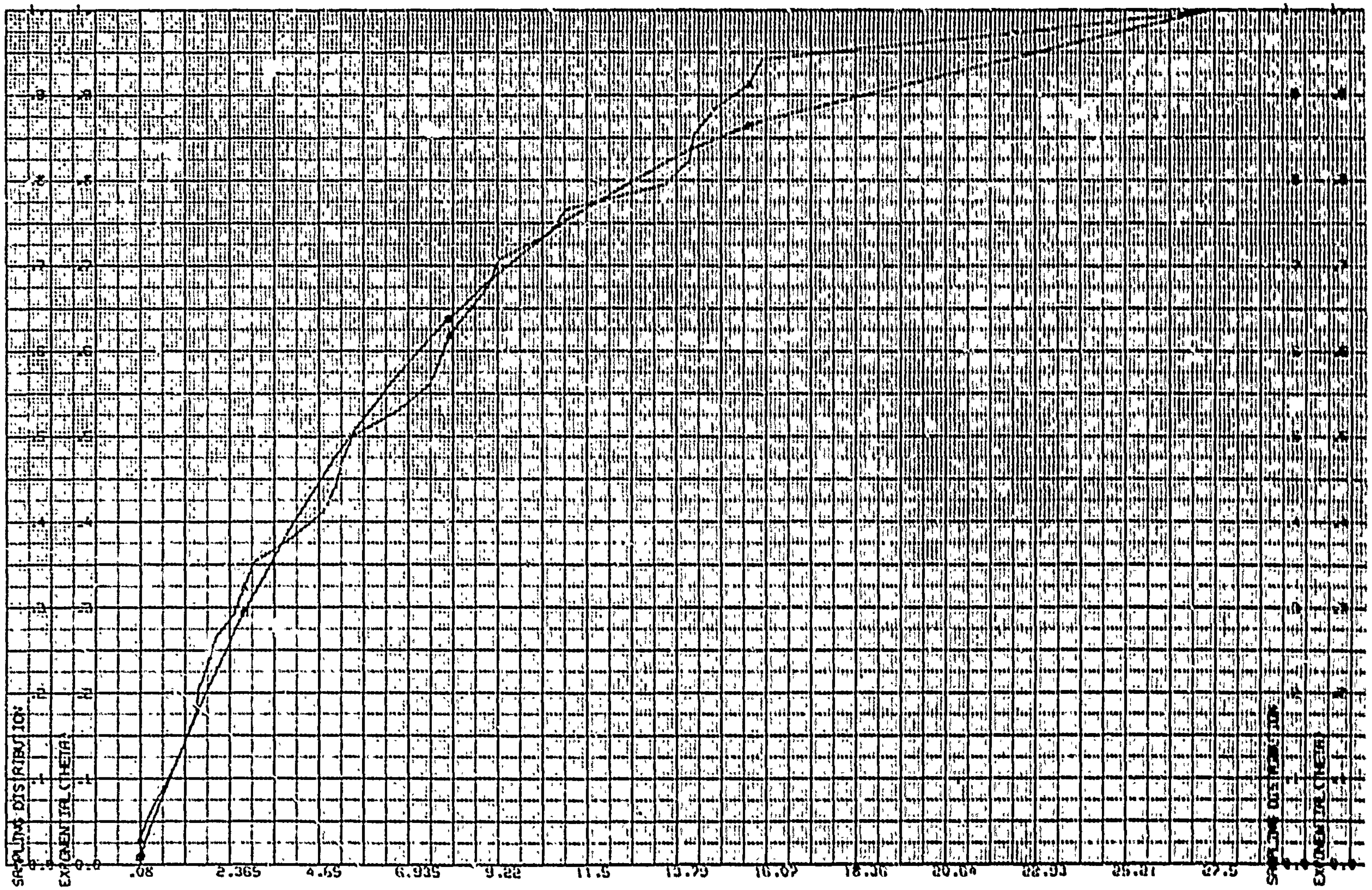

Figure 56. Test for Exponential Data: Critical LRU - Navigational Computer CP812/AJQ-20 Shop Active Hours WUC 73ABO

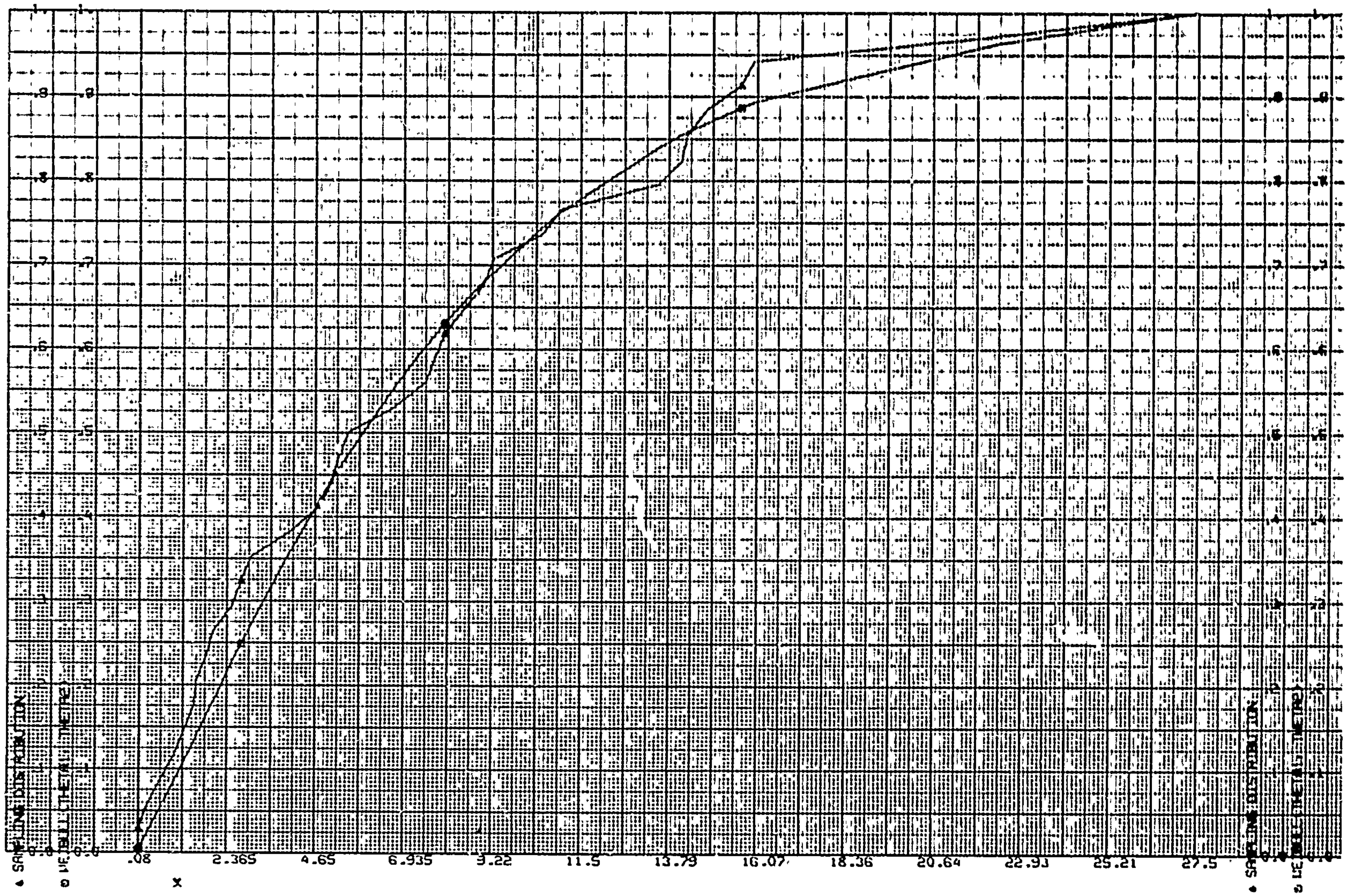

Figure 57. Test for Weibull Data: Critical LRU - Navigational Computer CP812/AJQ-20 Shop Active Hours WUC 73ABO

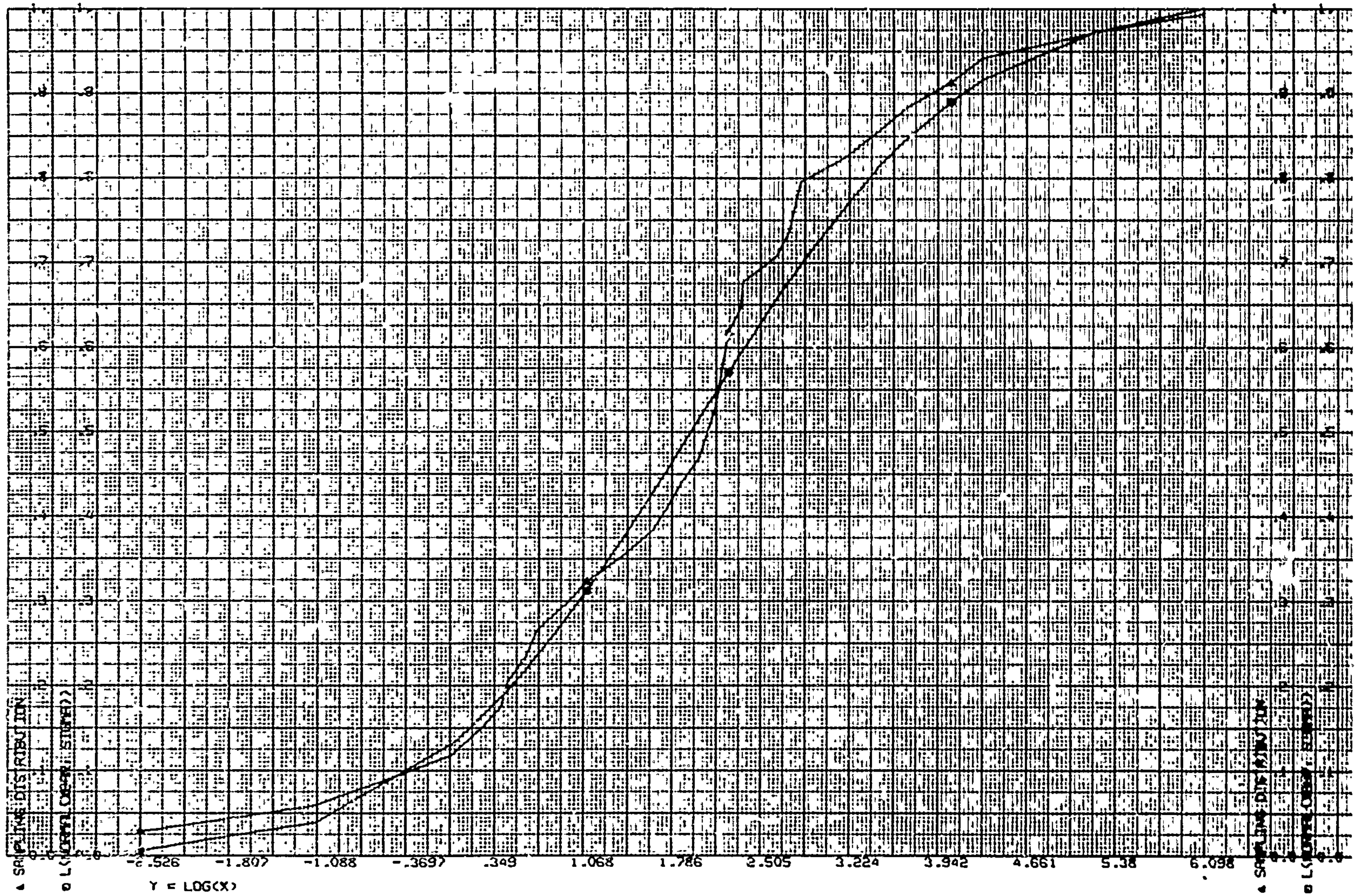

Figure 58. Test for Log Normality: Critical LRU - Navigational Computer CP812/AJQ-20 Shop Elapsed Hours WUC 73ABO

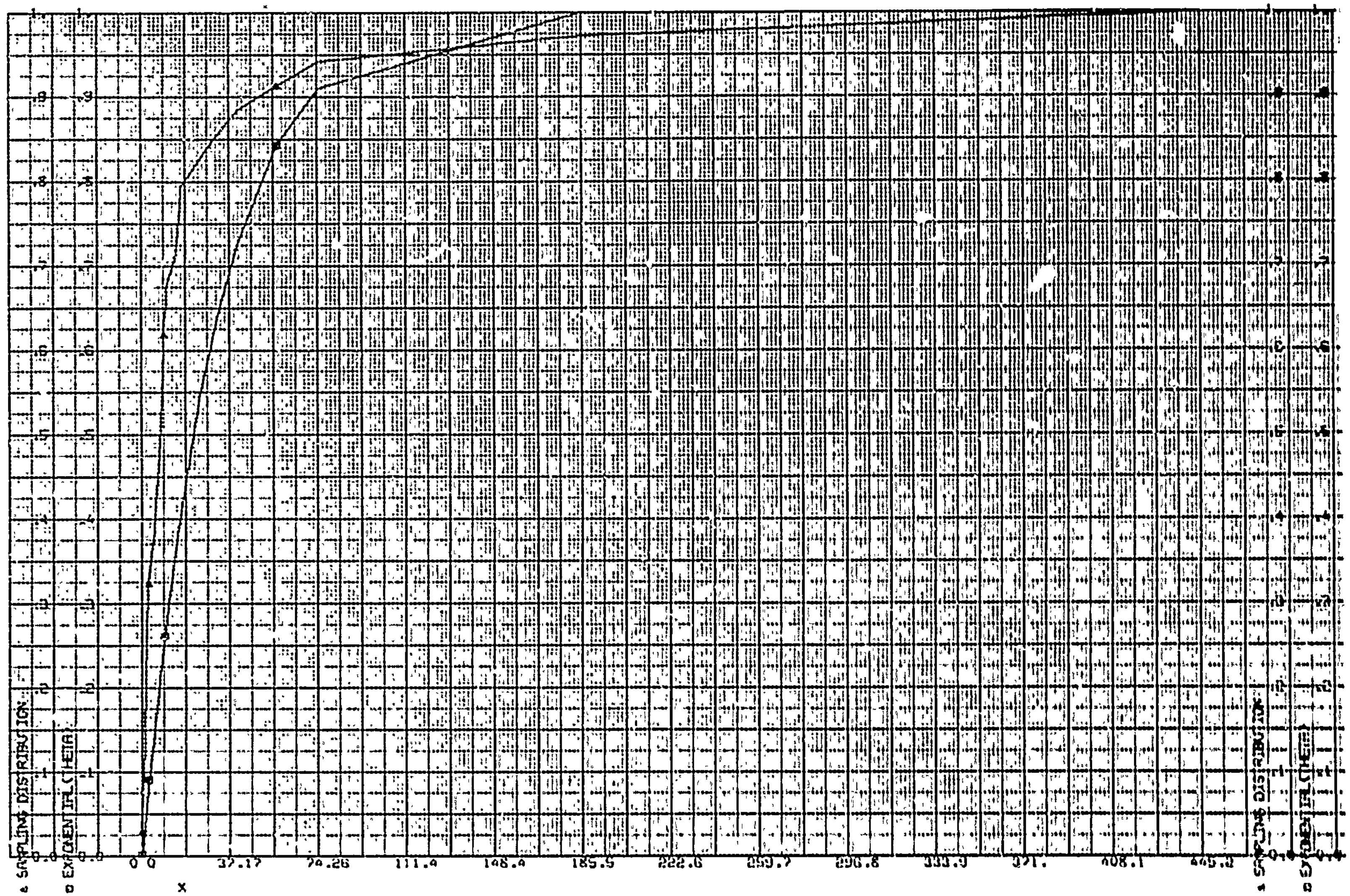

Figure 59. Test for Exponential Data: Critical LRU - Navigational Computer CP812/AJQ-20 Shop Elapsed Hours WUC 73ABO

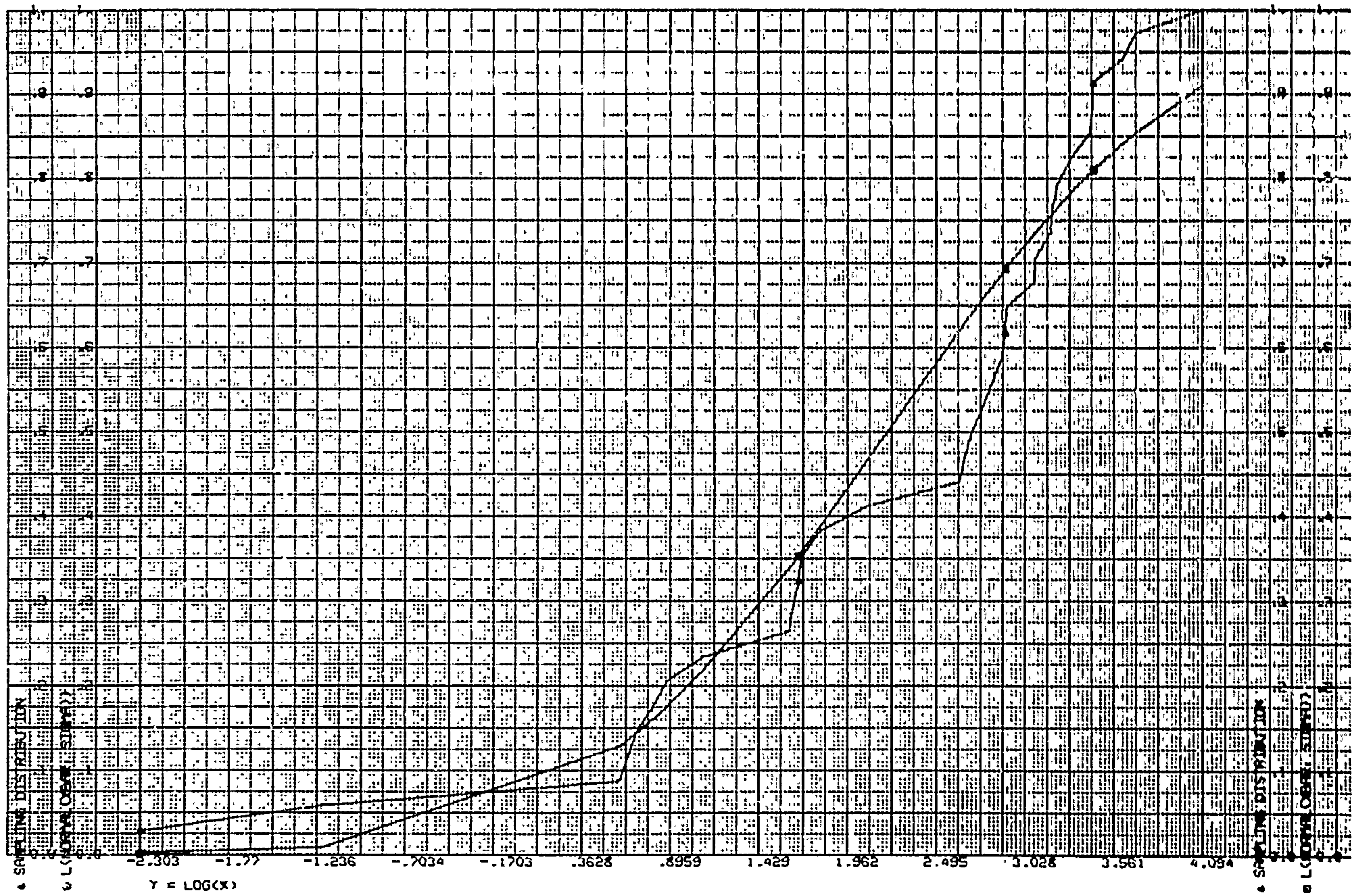

Figure 60. Test for Log Normality: Critical LRU - Navigational Computer CP812/AJQ-20 Shop Man Hours WUC 73ABO

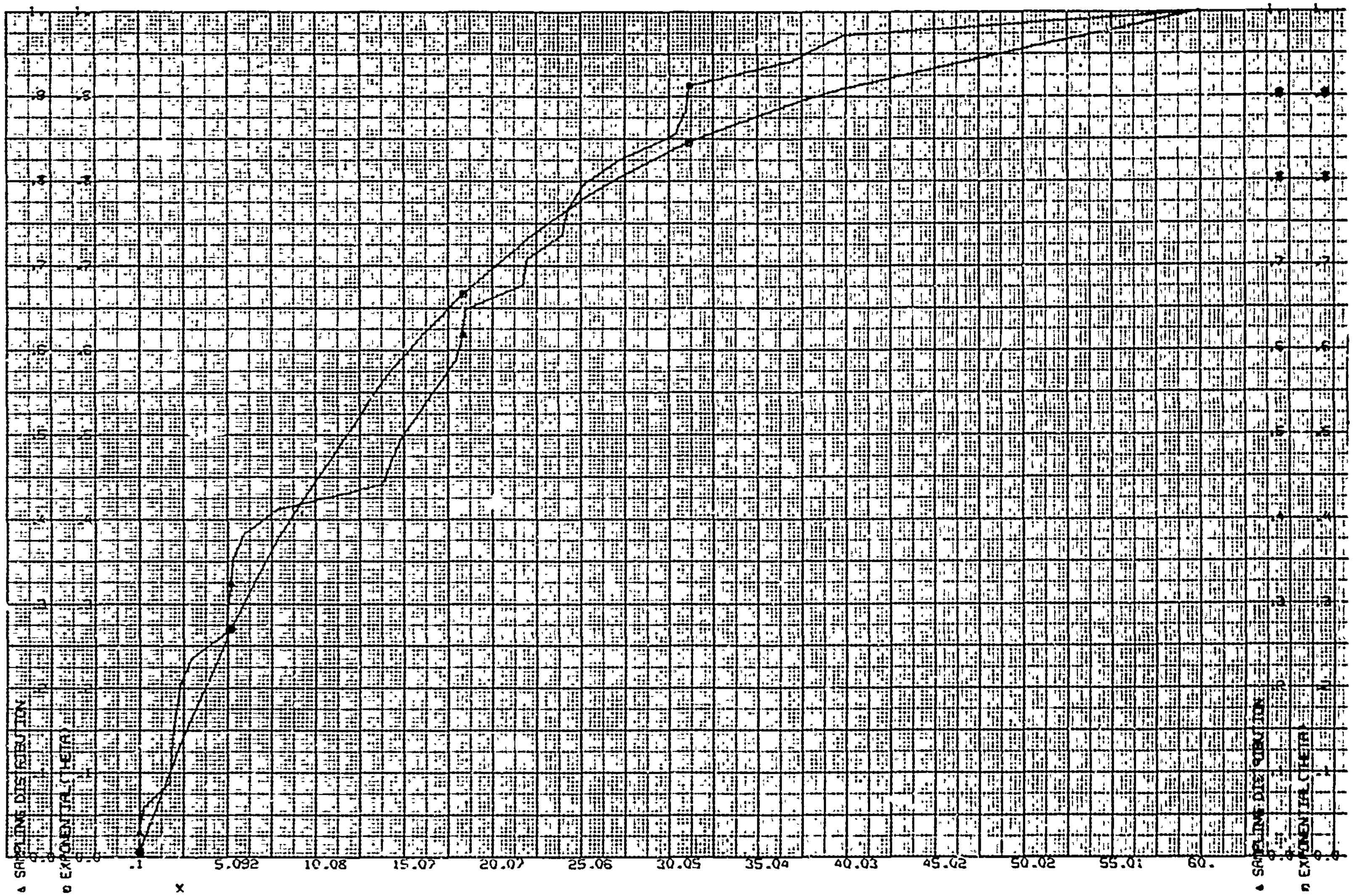

Figure 61. Test for Exponential Data: Critical LRU - Navigational Computer CP812/AJQ-20 Shop Man Hours WUC 73ABO

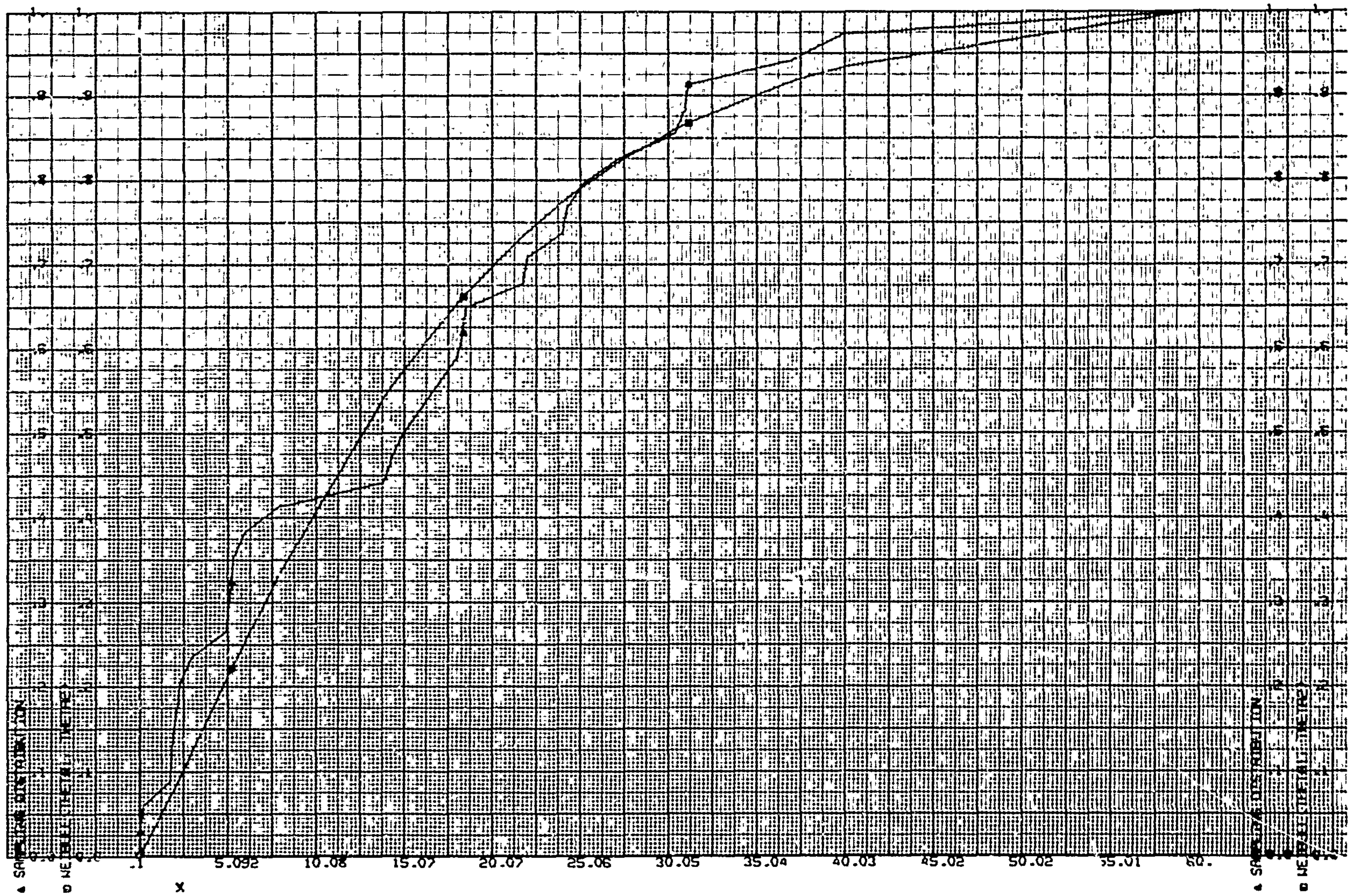

Figure 62. Test for Weibull Data: Critical LRU - Navigational Computer CP812/AJQ-20 Shop Man Hours WUC 73ABO

Table 8: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}: S_n(t) \equiv F(t\|\theta)$	Sample Size	$\bar{t}$	s_t	Graphs	D_n	$1 - Q(D_n\sqrt{n})$	Decision
Navigational Computer CP812/AJQ-20 WUC 73ABO Line Active Hours	L(N(1.24, 1.38)) E(0.1762) W(1.2280, 0.1135)	33 33 33	- 5.50 5.50	- 4.47 4.47	63 64 65	0.1404 0.1121 0.1115	0.5336 0.8016 0.8855	
Line Elapsed Hours	L(N(2.51, 4.00)) E(0.0191) W(0.5920, 0.1259)	33 33 33	- 50.73 50.73	- 90.71 90.71	66 67 68	0.0843 0.2914 0.0845	0.9732 0.0074 0.9724	Reject
Line Man Hours	L(N(1.97, 1.68)) E(0.0803) W(1.1030, 0.0615)	33 33 33	- 12.08 12.08	- 10.90 10.90	69 70 71	0.1672 0.1077 0.0923	0.3148 0.8383 0.9415	

Source: 258 Data System for F-111, Edwards AFB, California.

See Table 1 for definition of $L(N(\mu,\sigma^2))$, $E(\lambda)$ and $W(\beta,\lambda)$.

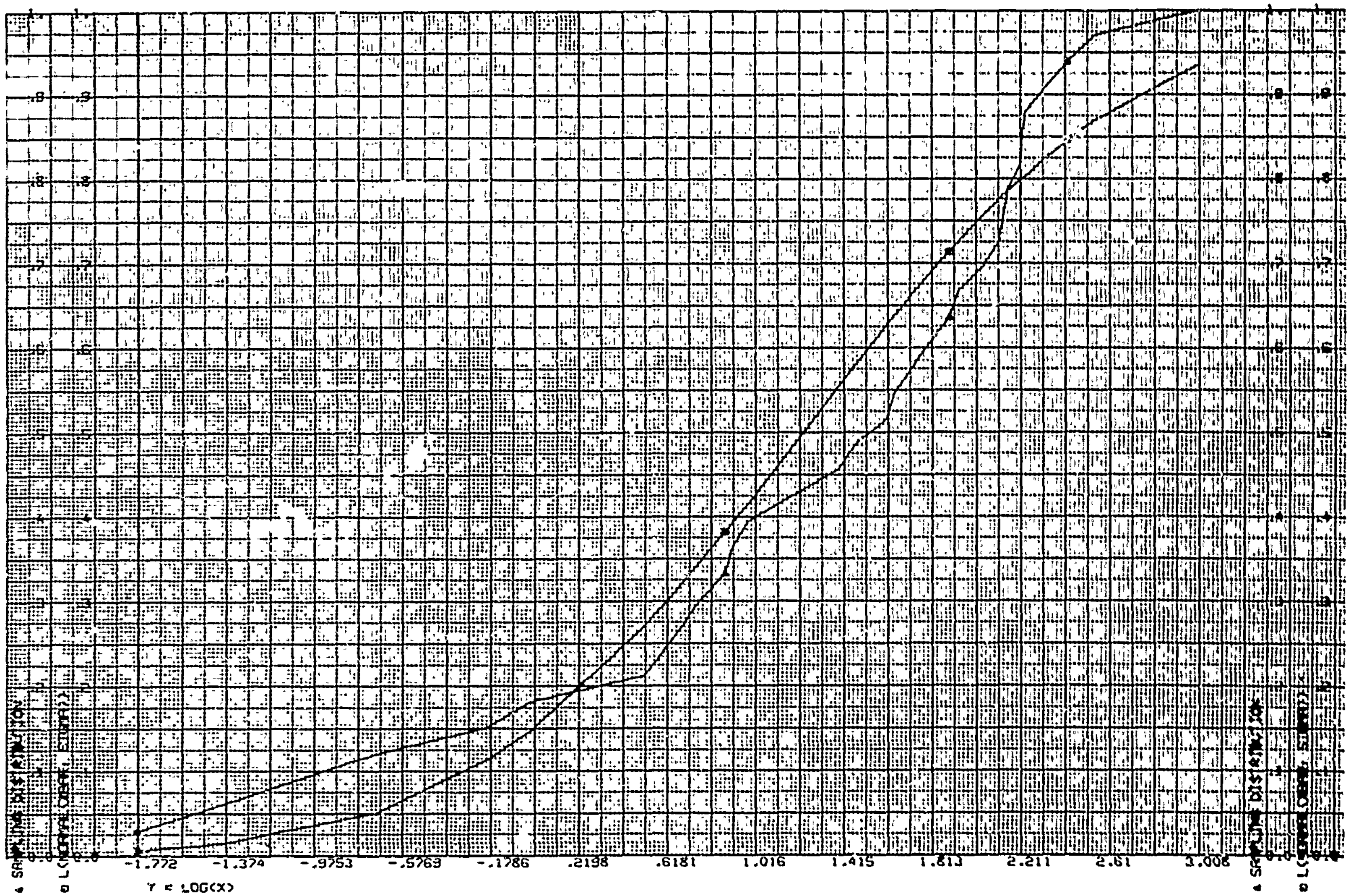

Figure 63. Test for Log Normality: Critical LRU - Navigational Computer CP812/AJQ-20 Line Active Hours WUC 73ABO

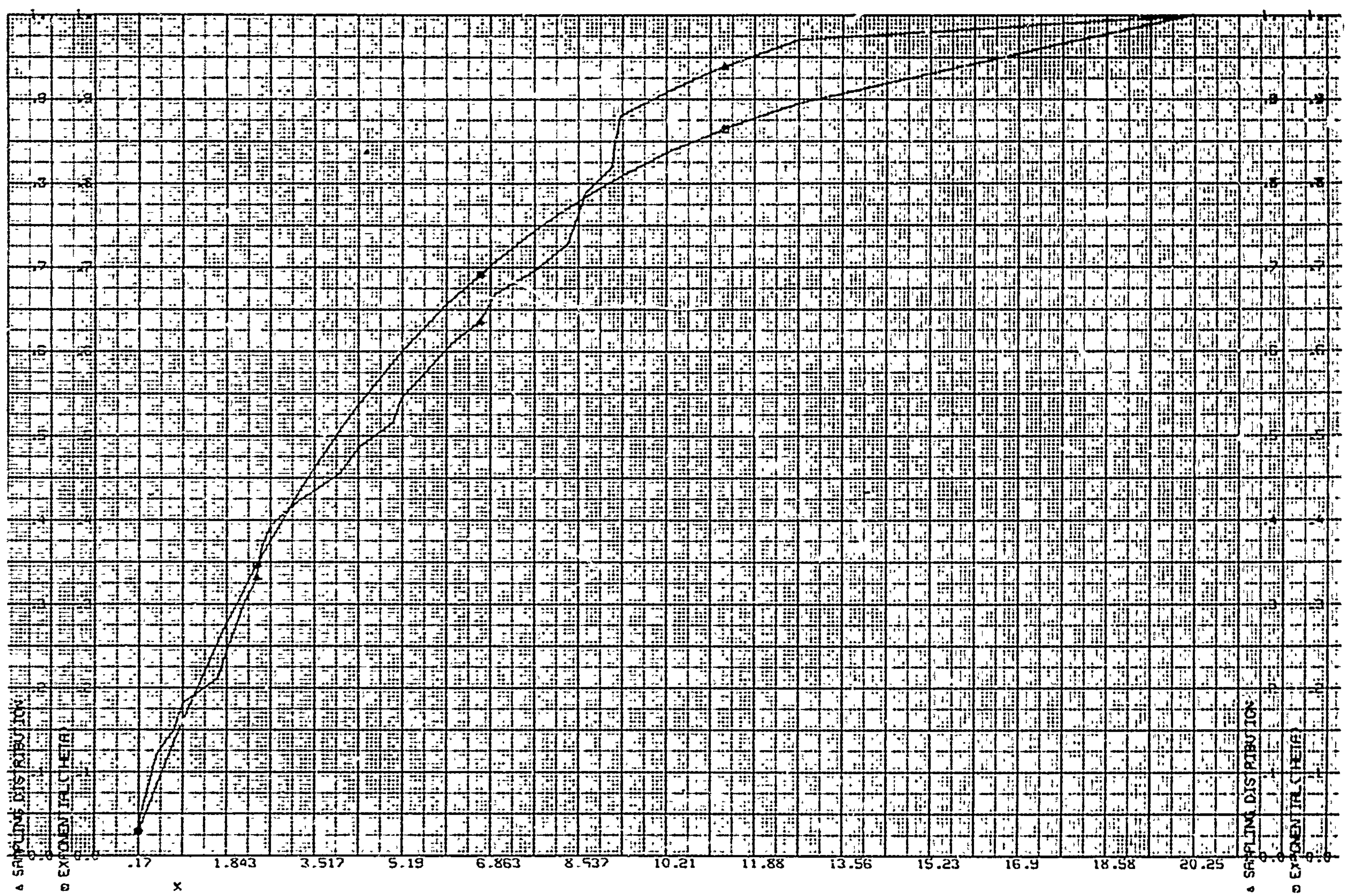

Figure 64. Test for Exponential Data: Critical LRU - Navigational Computer CP812/AJQ-20 Line Active Hours WUC 73ABO

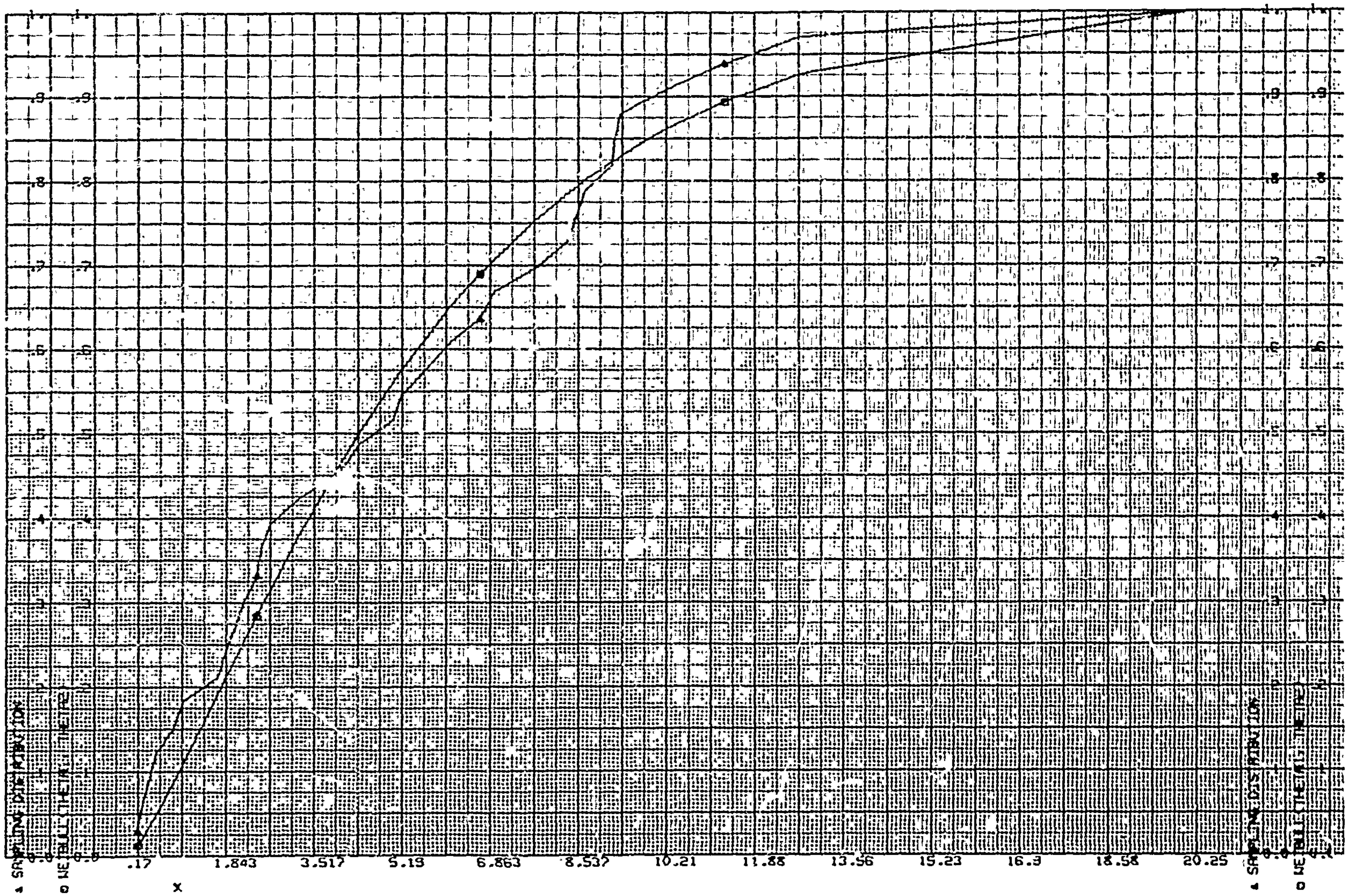

Figure 65. Test for Weibull Data: Critical LRU - Navigational Computer CP812/AJQ-20 Line Active Hours WUC 73ABO

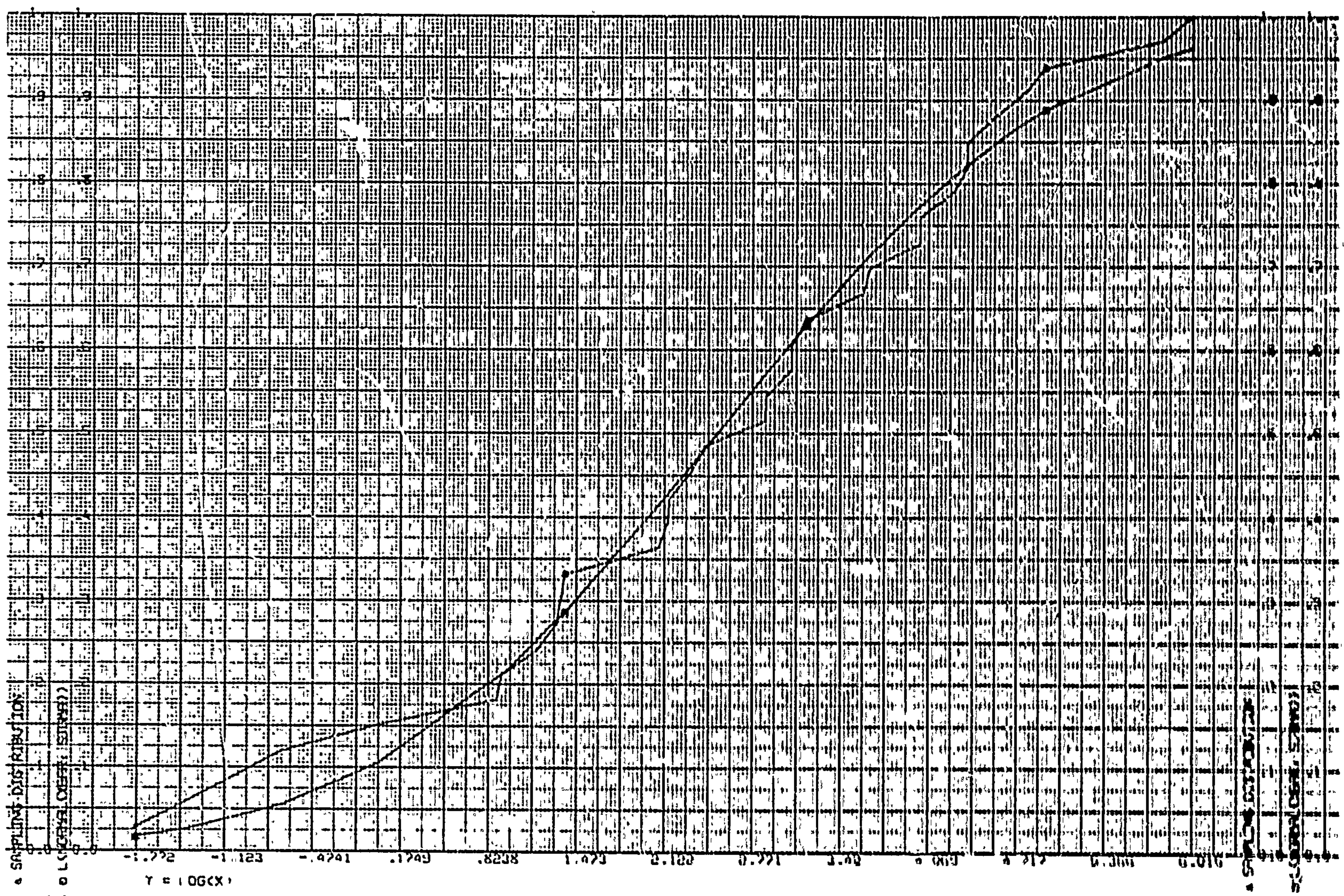

Figure 66. Test for Log Normality: Critical LRU - Navigational Computer CP812/AJQ-20 Line Elapsed Hours WUC 73ABO

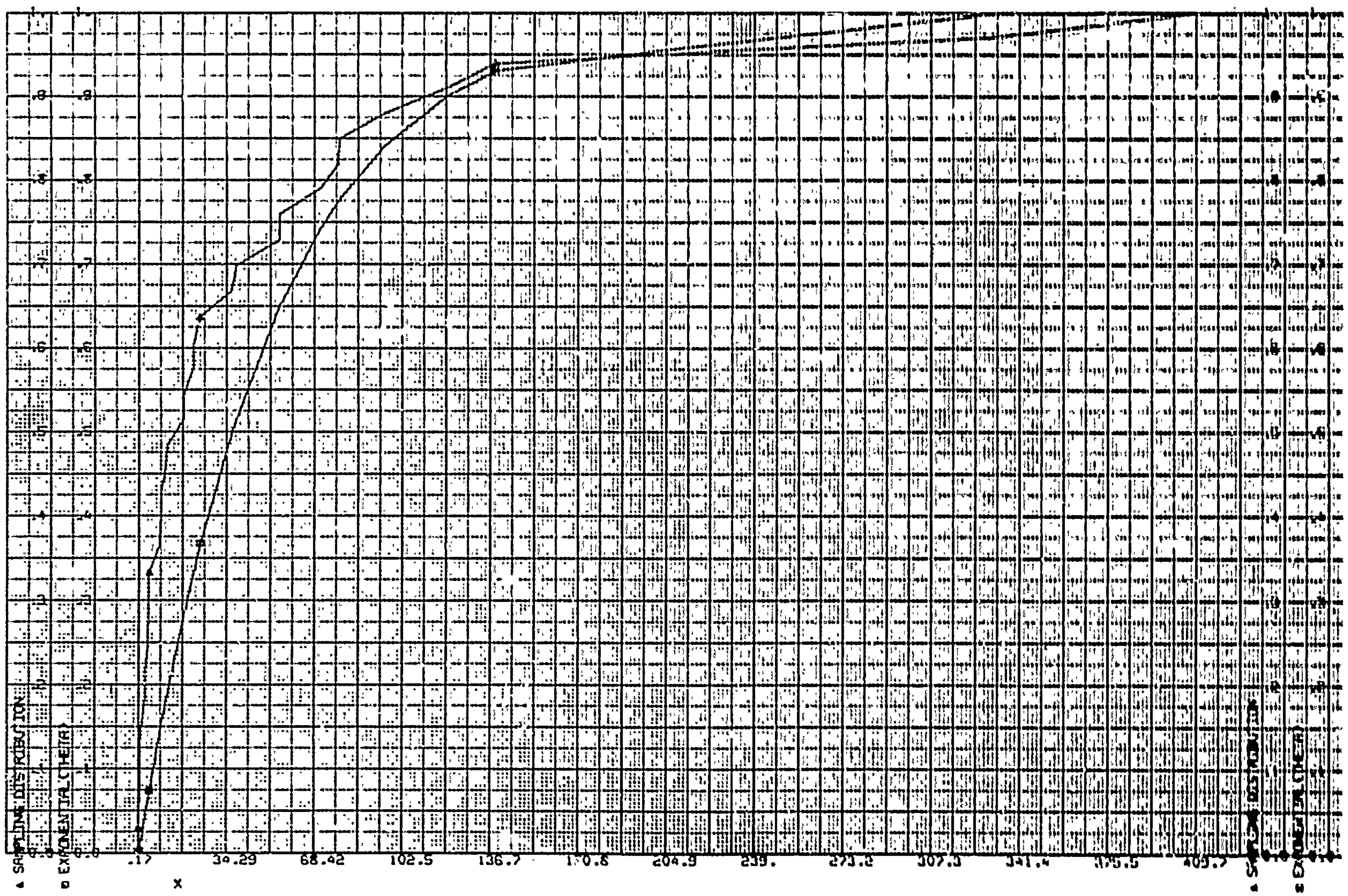

Figure 67. Test for Exponential Data: Critical LRU - Navigational Computer CP812/AJQ-20 Line Elapsed Hours WUC 73ABO

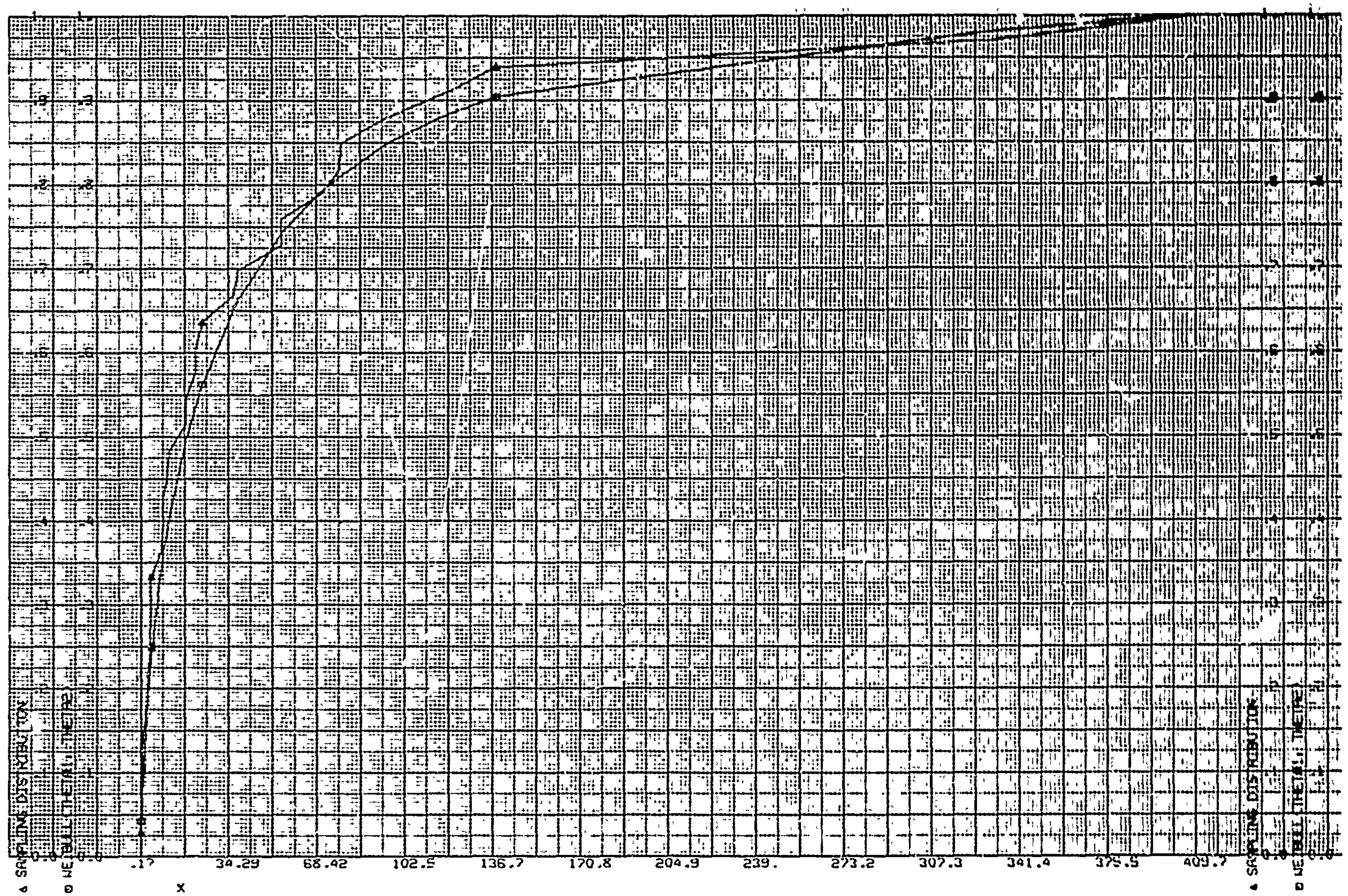

Figure 68. Test for Weibull Data: Critical LRU - Navigational Computer CP812/AJQ-20 Line Elapsed Hours WUC 73ABO

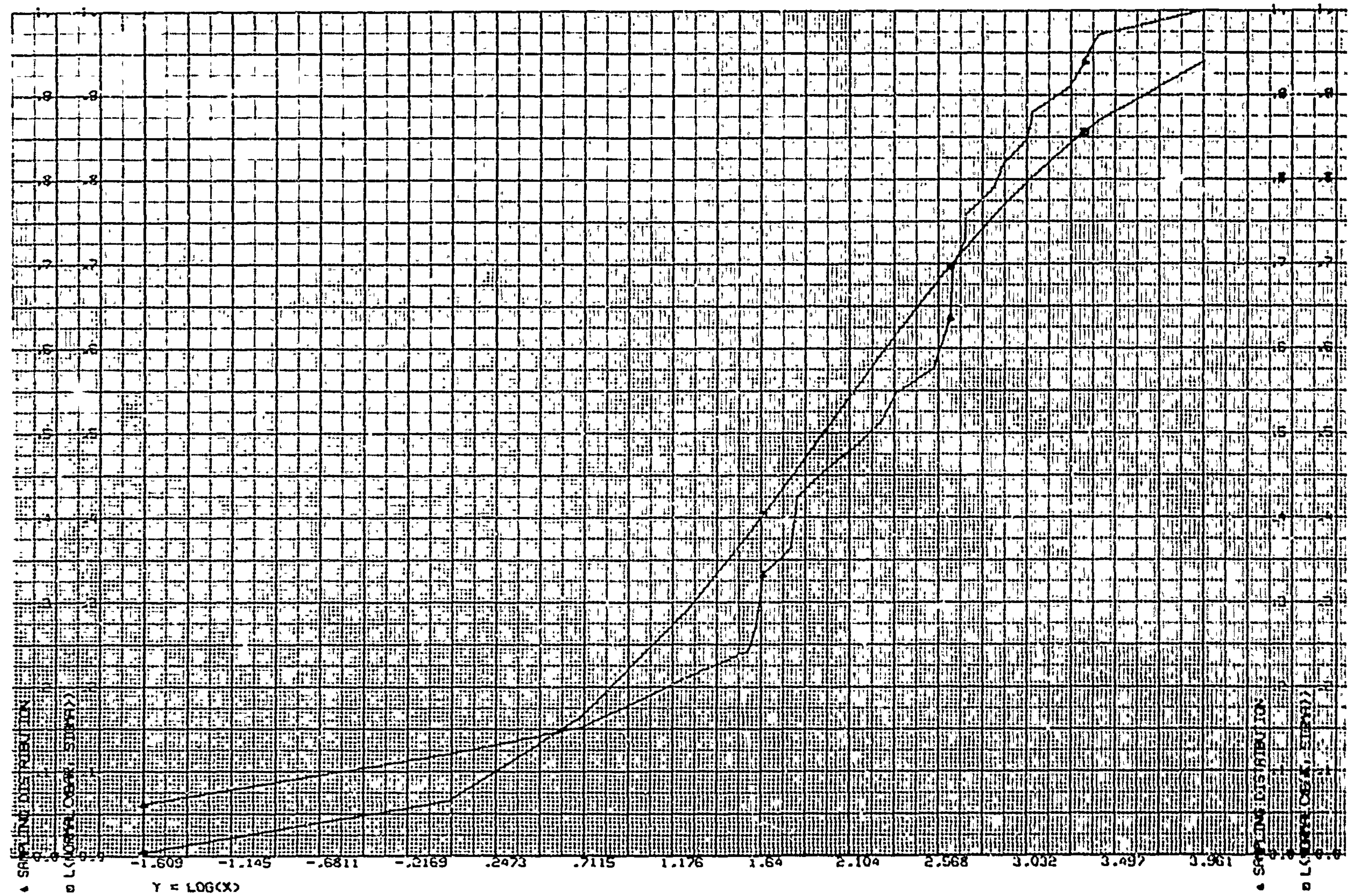

Figure 69. Test for Log Normality: Critical LRU - Navigational Computer CP812/AJQ-20 Line Man Hours WUC 73ABO

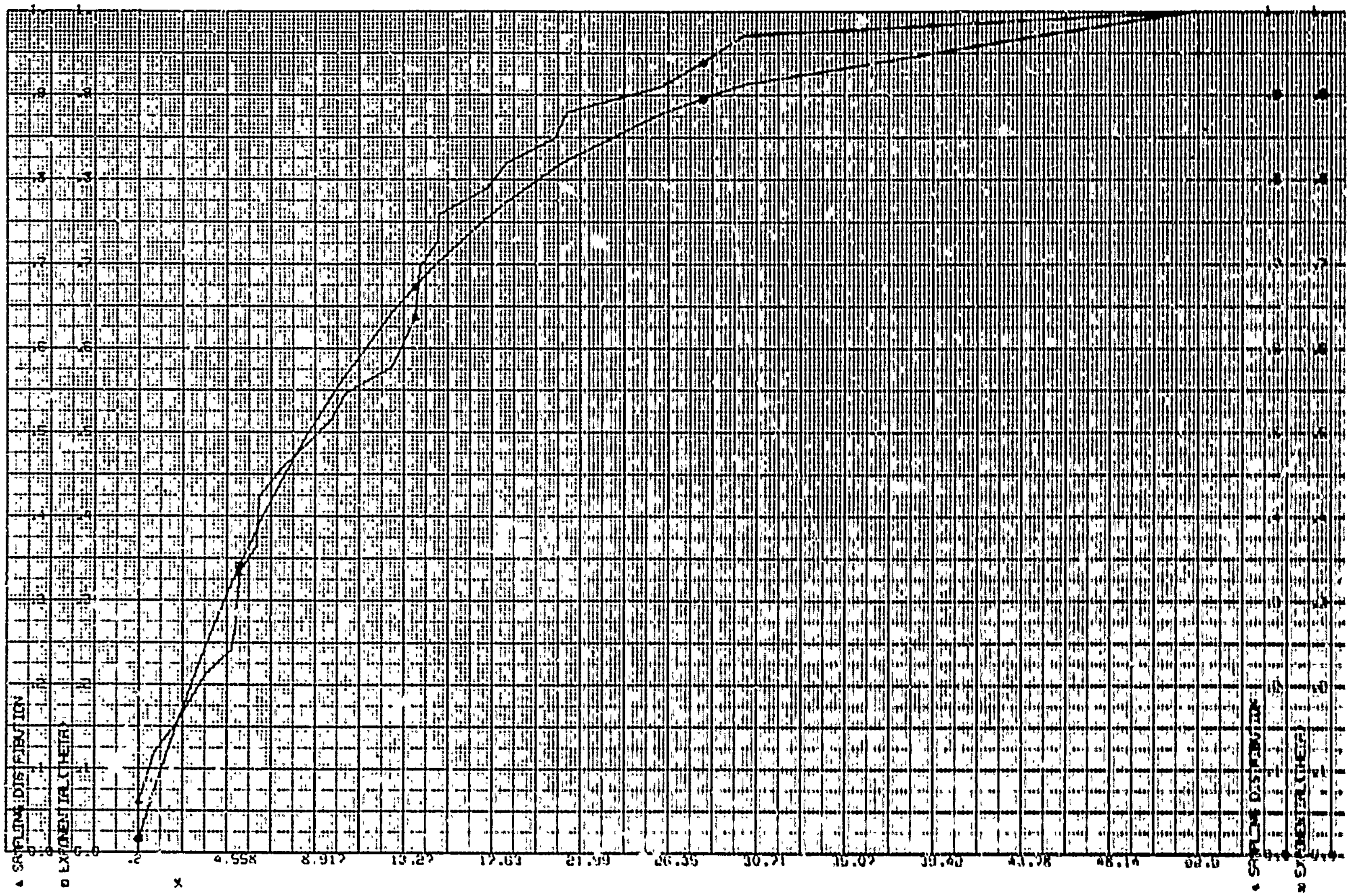

Figure 70. Test for Exponential Data: Critical LRU - Navigational Computer CP812/AJQ-20 Line Man Hours WUC 73ABO

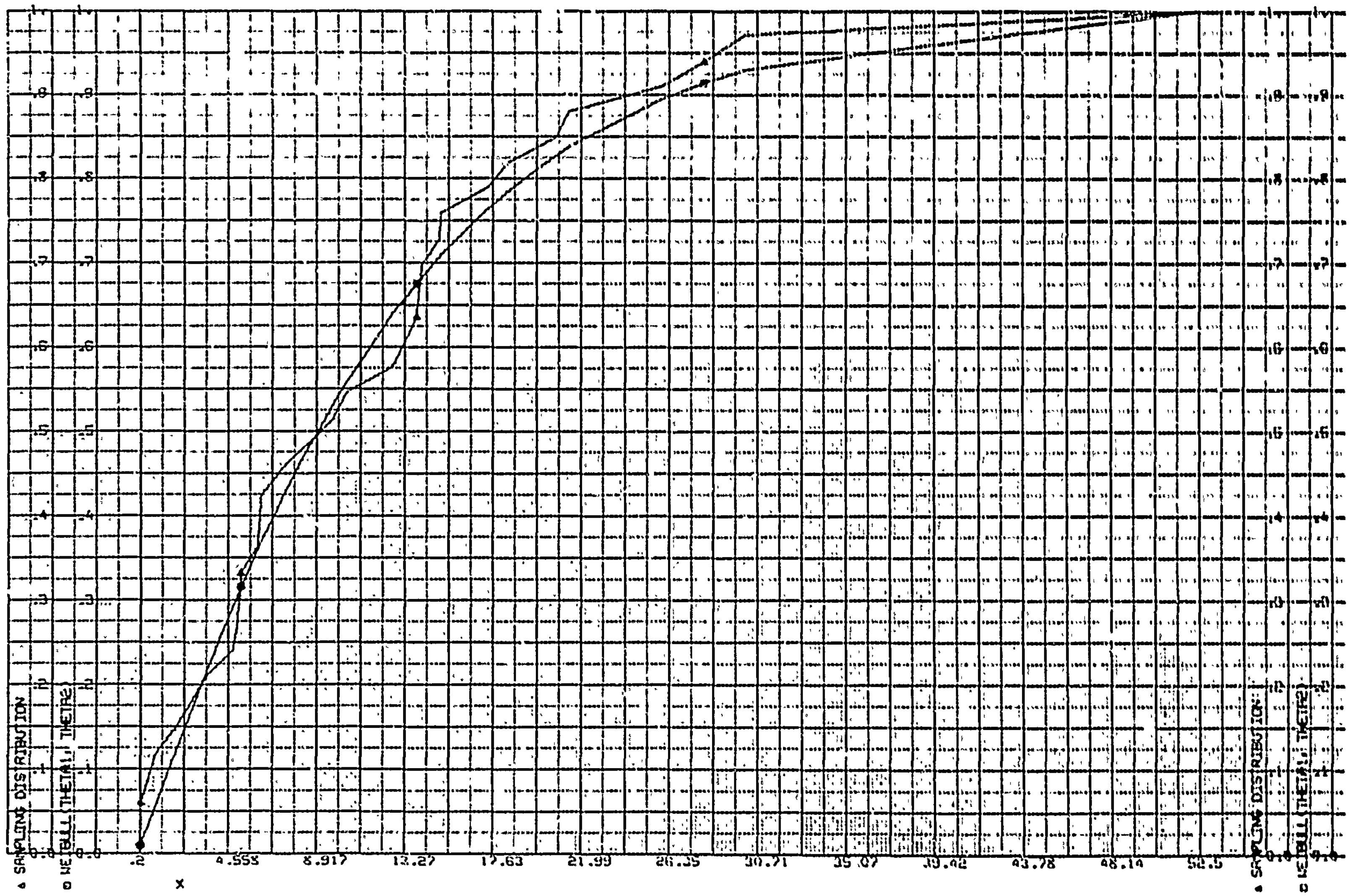

Figure 71. Test for Weibull Data: Critical LRU - Navigational Computer CP812/AJQ-20 Line Man Hours WUC 73ABO

Table 9: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}: S_n(t) \equiv F(t\|\theta)$	Sample Size	$\bar{t}$	s_t	Graph	D_n	$1 - Q(D_n\sqrt{n})$	Decision
Shop active hours for all critical LRU's combined.	L(N(0,1))	122	-	-	72	0.5954	0.0000	Reject
	L(N(1.64, 1.32))	122	-	-	72	0.0644	0.6926	
	E(0.1065)	122	9.31	12.59	73	0.0876	0.3059	
	W(0.7490, 0.2143)	122	9.31	12.59	74	0.1392	0.0177	Reject
Shop elapsed hours for all critical LRU's combined.	L(N(0,1))	122	-	-	75	0.6427	0.0000	Reject
	L(N(2.42, 3.75))	122	-	-	75	0.1119	0.0943	
	E(0.0127)	122	77.86	204.11	76	0.5020	0.0000	Reject
	W*	122	77.86	204.11	-	-	-	
Shop man hours for all critical LRU's combined.	L(N(0,1)	122	-	-	77	0.7009	0.0000	Reject
	L(N(2.18, 1.71))	122	-	-	77	0.1001	0.1738	
	E(0.0593)	122	16.73	18.24	78	0.0675	0.6342	
	W(0.9150, 0.0789)	122	16.73	18.24	79	0.0421	0.9821	

Source: 258 Data System for the F-111, Edwards AFB, California.

See Table 1 for definition of $L(N(\mu,\sigma^2))$, $E(\lambda)$ and $W(\beta,\lambda)$.

*No fit possible.

[1] LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO not included.

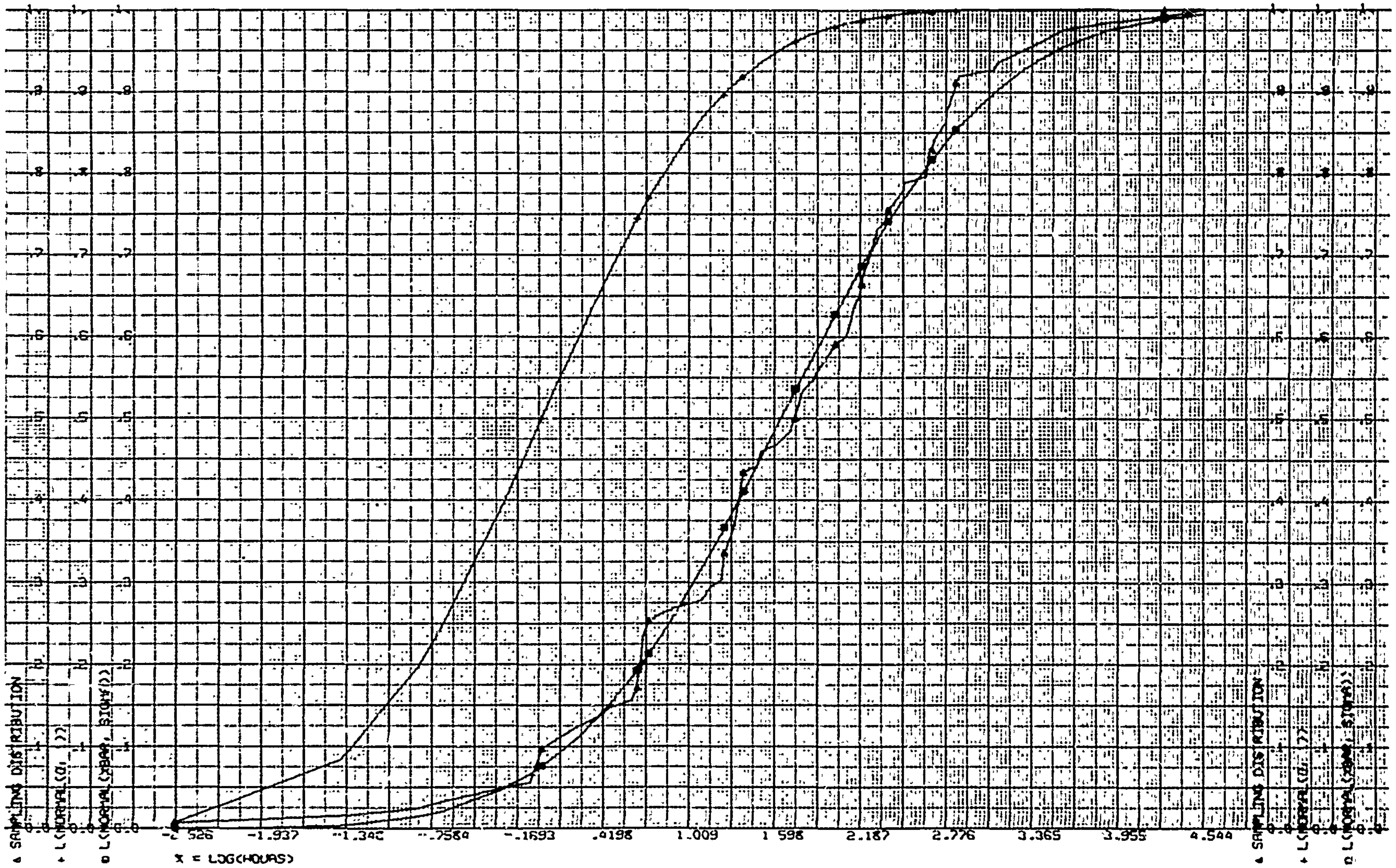

Figure 72. Test for Log Normality: All Critical LRU's Combined - Shop Active Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

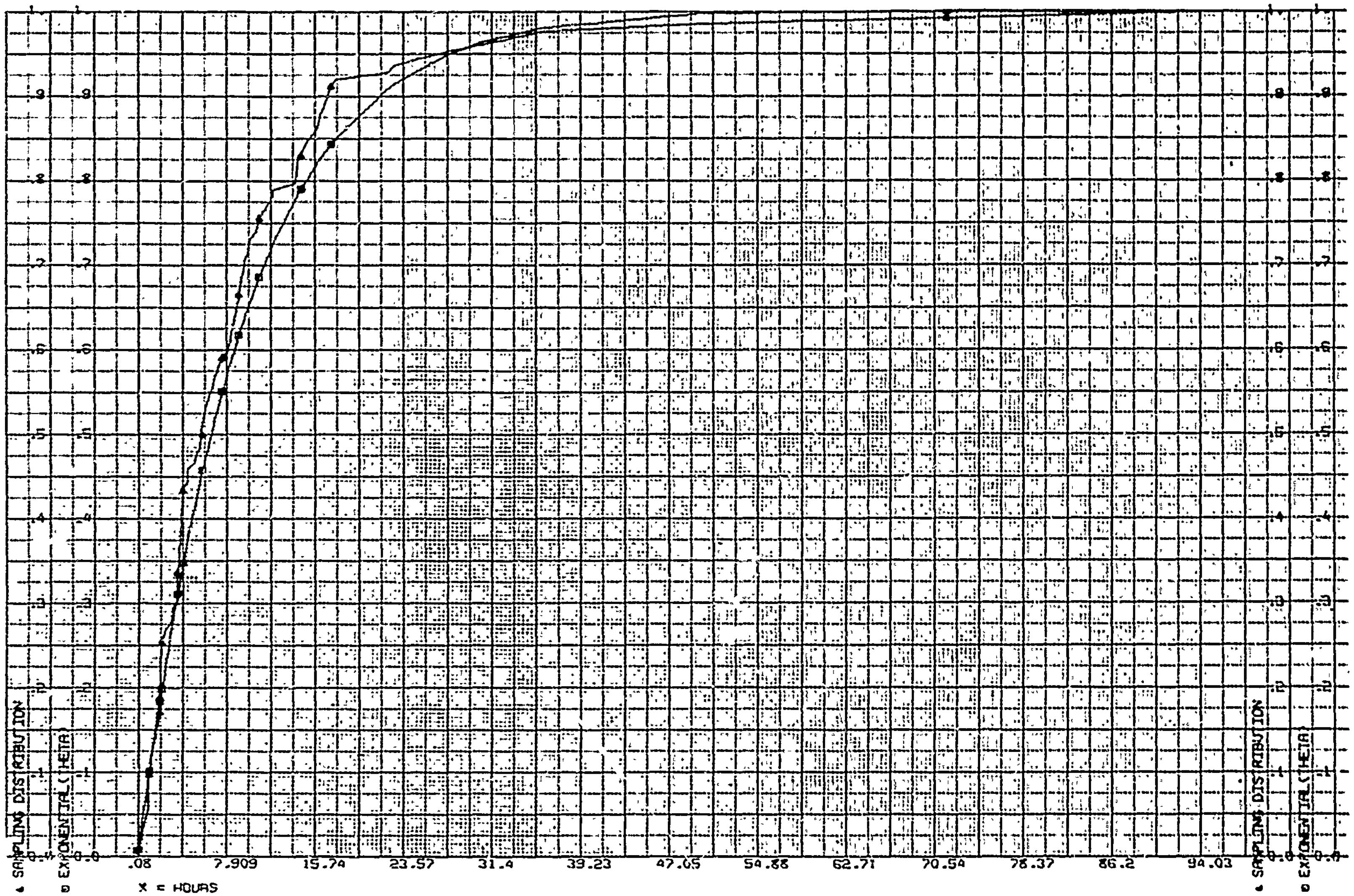

Figure 73. Test for Exponential Data: All Critical LRU's Combined - Shop Active Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

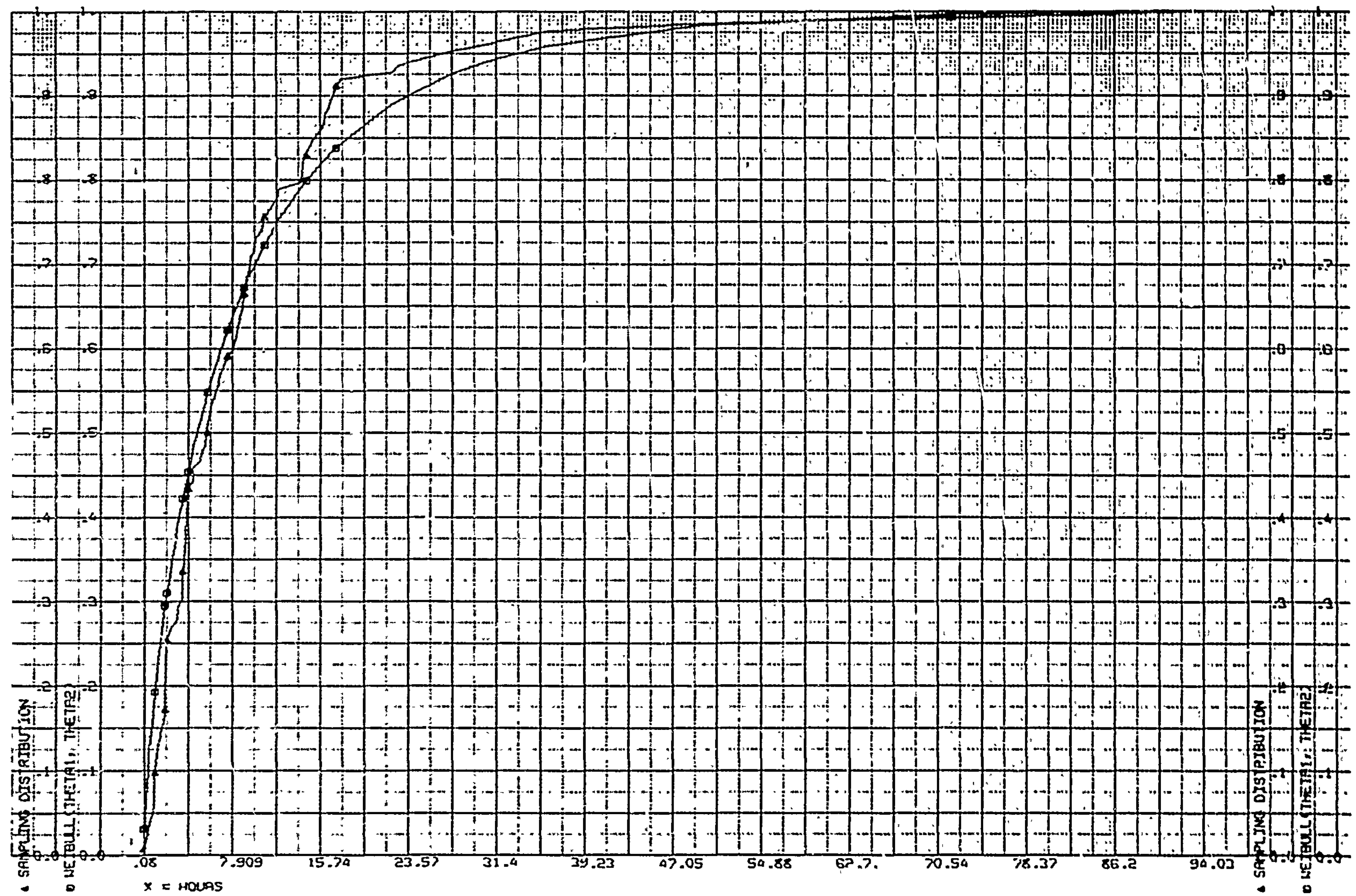

Figure 74. Test for Weibull Data: All Critical LRU's Combined - Shop Active Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

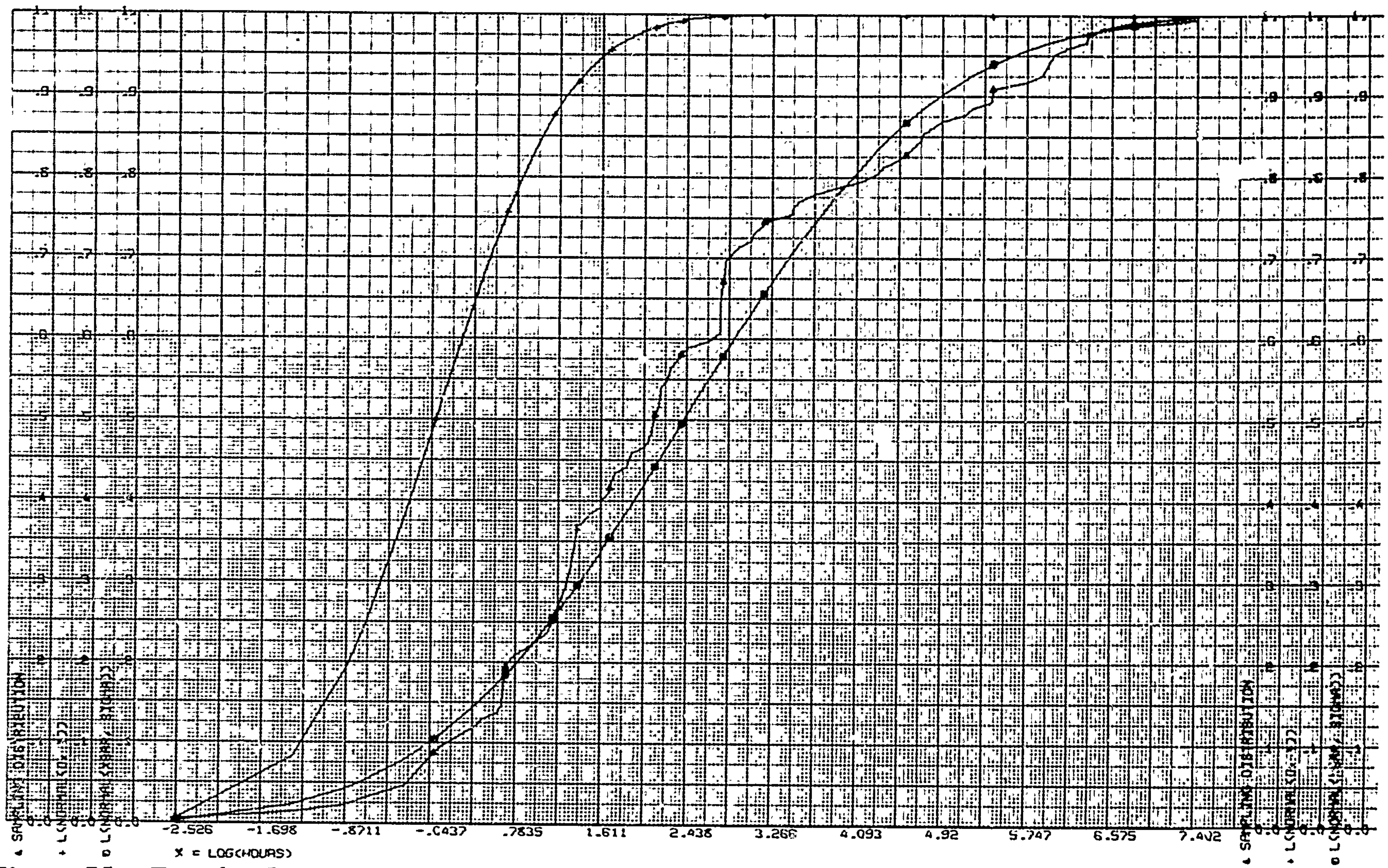

Figure 75. Test for Log Normality: All Critical LRU's Combined - Shop Elapsed Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

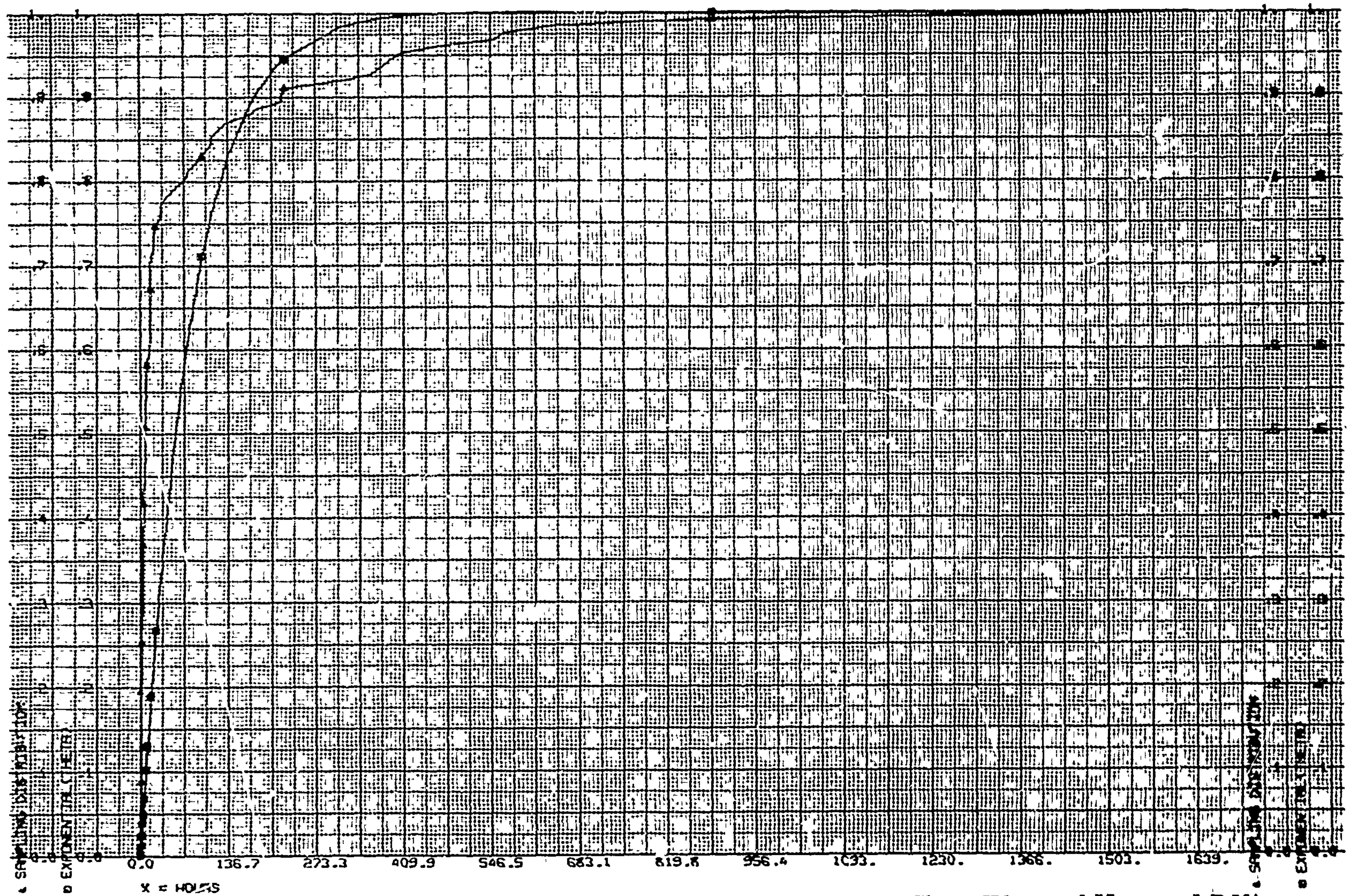

Figure 76. Test for Exponential Data: All Critical LRU's Combined - Shop Elapsed Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

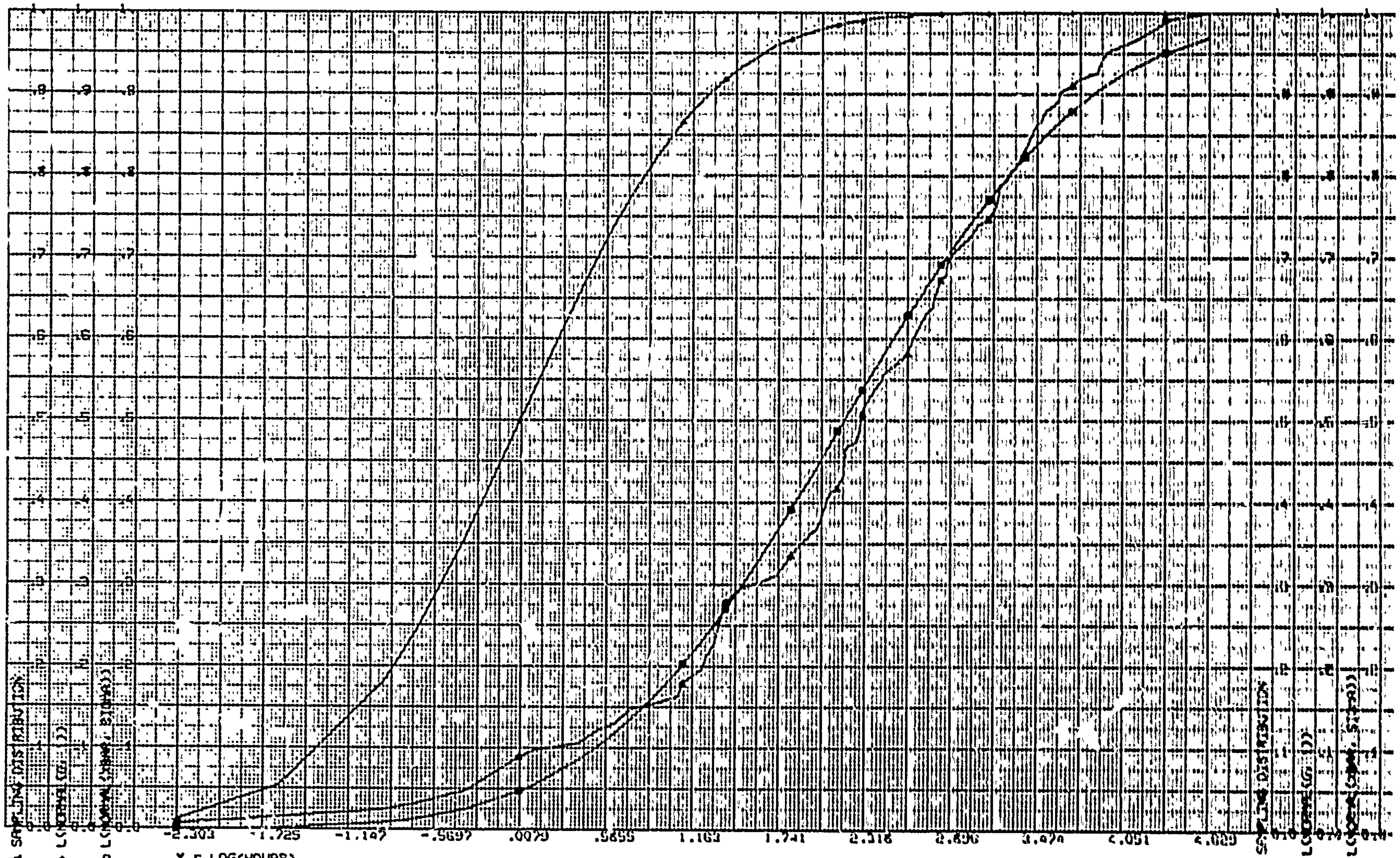

Figure 77. Test for Log Normality: All Critical LRU's Combined - Shop ManHours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

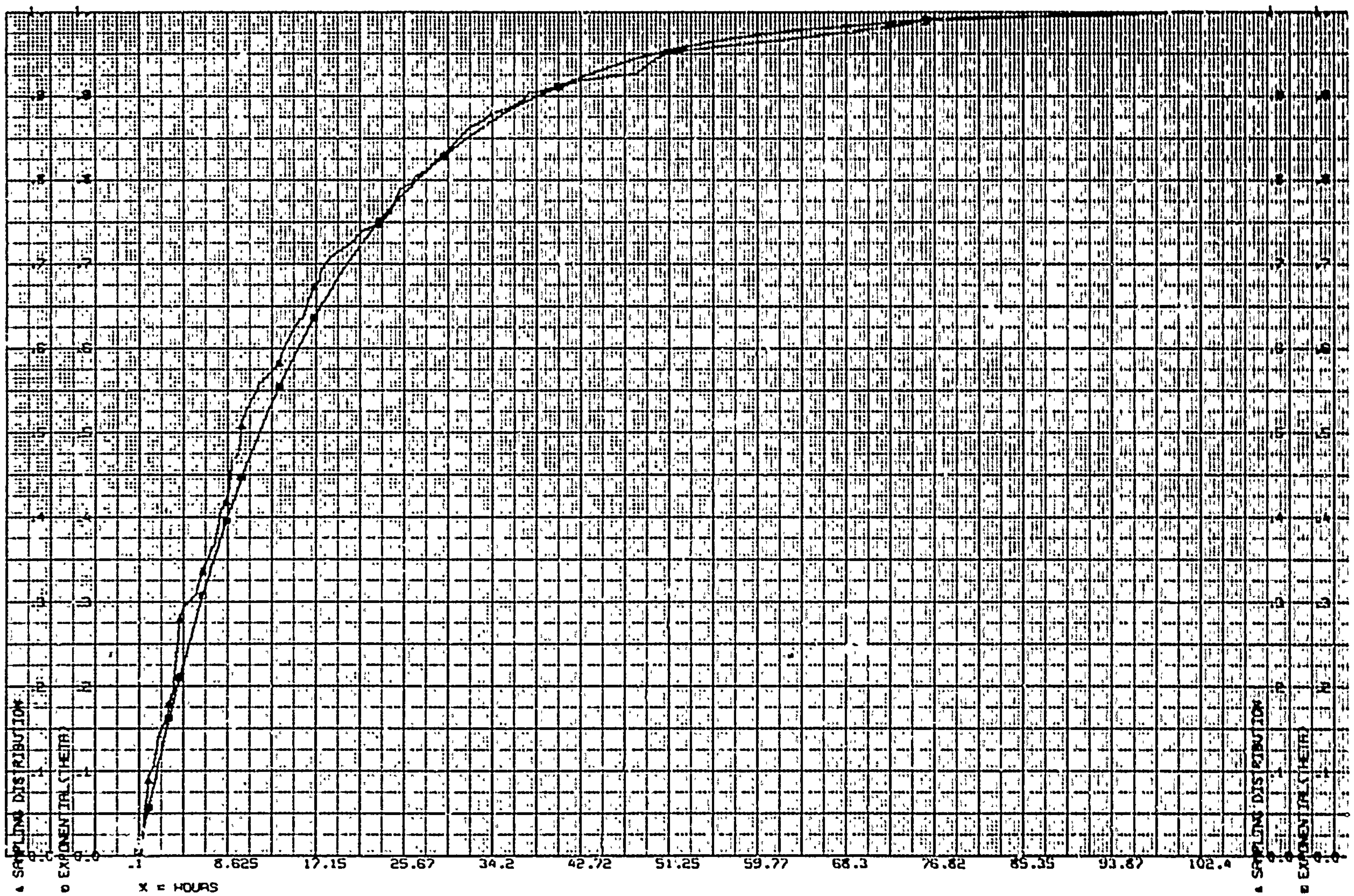

Figure 78. Test for Exponential Data: All Critical LRU's Combined - Shop ManHours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

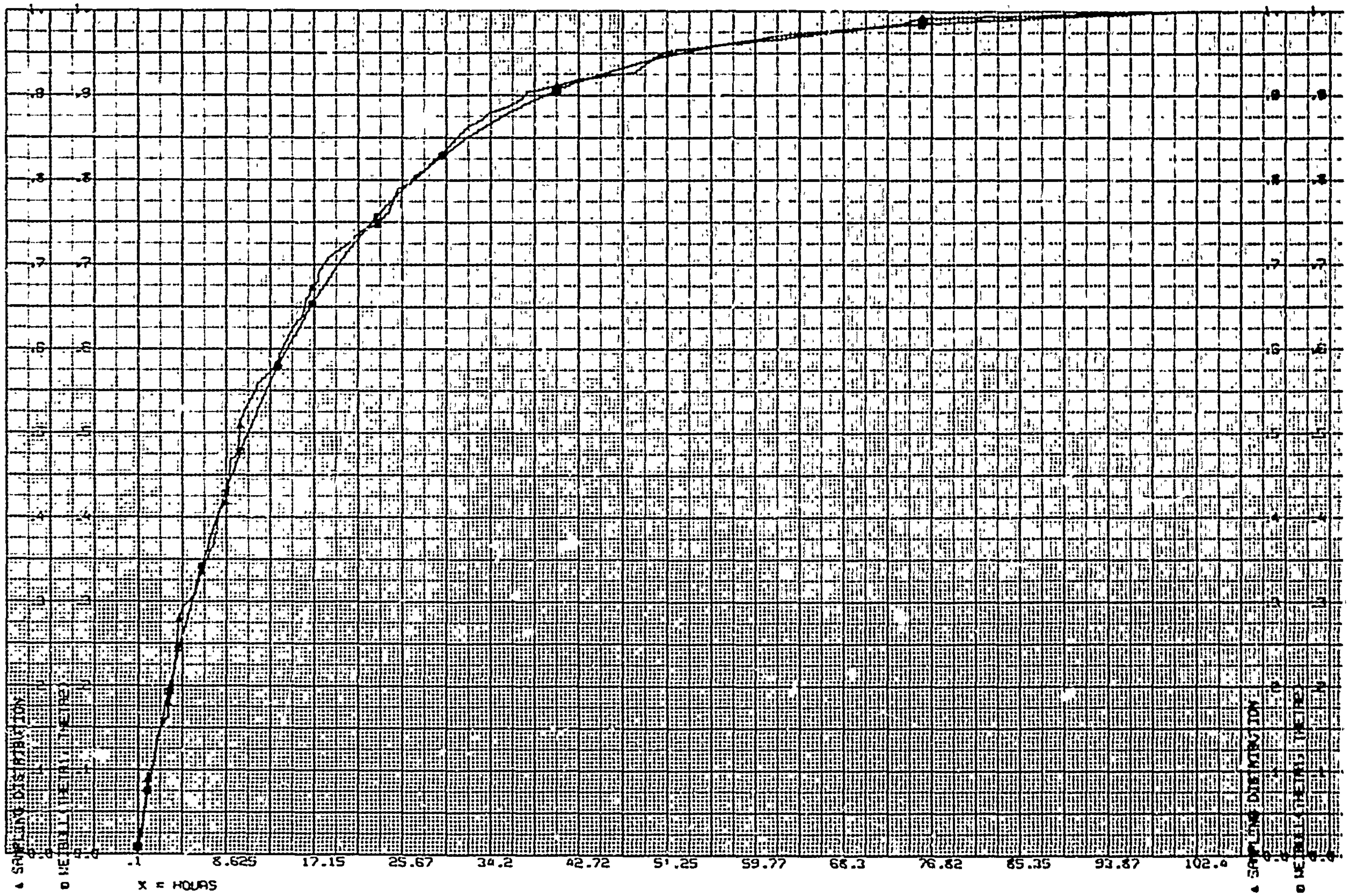

Figure 79. Test for Weibull Data: All Critical LRU's Combined - Shop Man Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

Table 10: Decision to reject the null hypothesis that the sample distribution function approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}$: $S_n(t) \equiv F(t\|\theta)$	Sample Size	$\bar{t}$	s_t	Graph	D_n	$1 - Q(D_n\sqrt{n})$	Decision
Line active hours for all critical LRU's combined.	L(N(0,1))	114	-	-	80	0.5279	0.0000	Reject
	L(N(1.21, 0.81))	114	-	-	80	0.0498	0.9398	
	E(0.2024)	114	4.90	4.71	81	0.1270	0.0504	
	W(1.0350, 0.1904)	114	4.90	4.71	82	0.1168	0.0892	
Line elapsed hours for all critical LRU's combined.	L(N(0,1))	114	-	-	83	0.6754	0.0000	Reject
	L(N(2.60, 3.03))	114	-	-	83	0.0309	0.4450	
	E(0.0207)	114	47.82	91.37	84	0.2791	0.0000	Reject
	W(0.5620, 0.1506)	114	47.82	91.37	85	0.09556	0.2486	
Line man hours for all critical LRU's combined.	L(N(0,1))	114	-	-	86	0.6905	0.0000	Reject
	L(N(1.90, 1.24))	114	-	-	86	0.0870	0.3542	
	E(0.0826)	114	11.99	17.58	87	0.1292	0.0444	Reject
	W(0.6980, 0.2085)	114	11.99	17.58	88	0.1981	0.0003	Reject

Source: 258 Data System for F-111, Edwards AFB, California

See Table 1 for definition of $L(N(\mu,\sigma^2))$, $E(\lambda)$ and $W(\theta,\lambda)$.

[1] LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO not included.

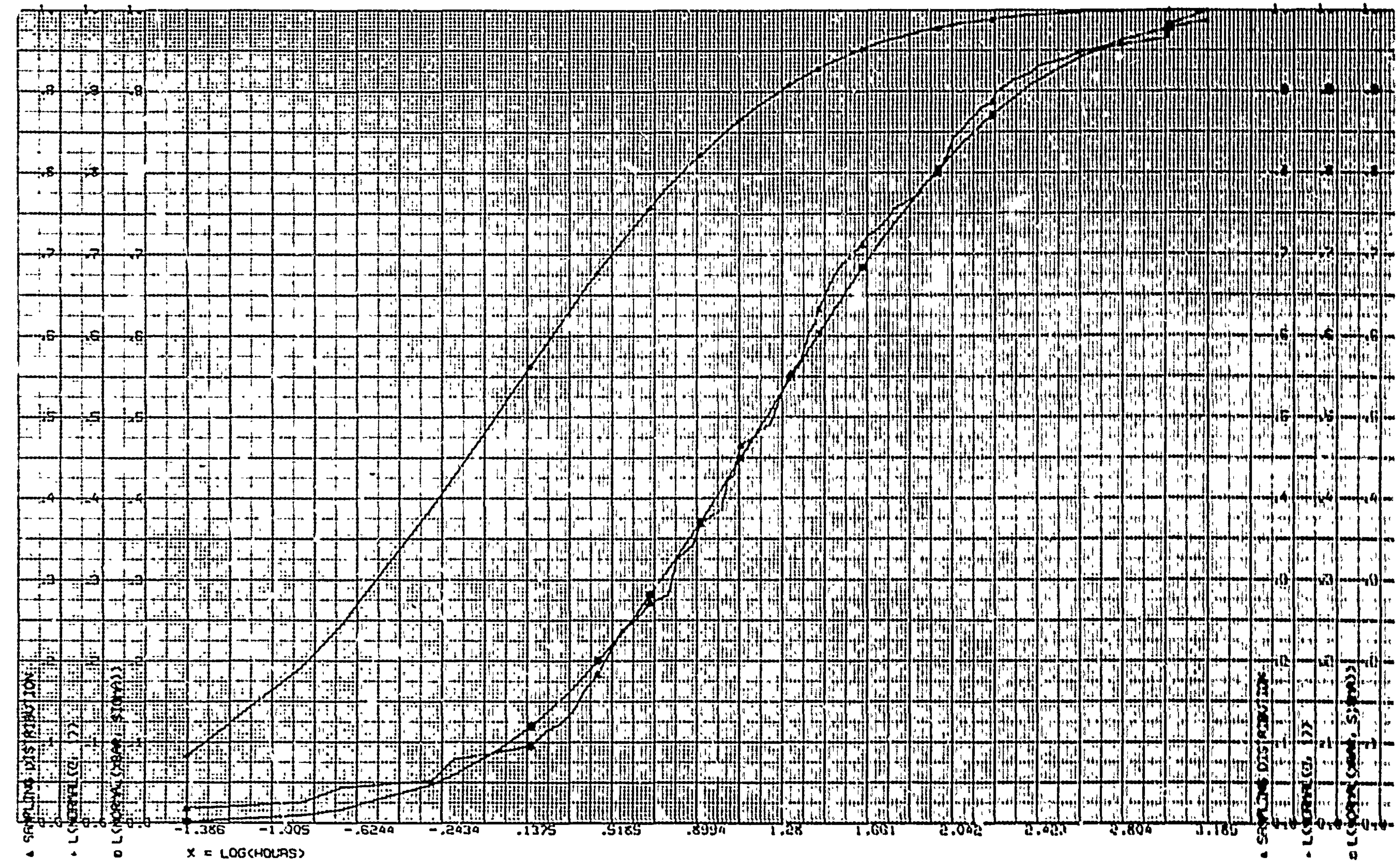

Figure 80. Test for Log Normality: All Critical LRU's Combined - Line Active Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

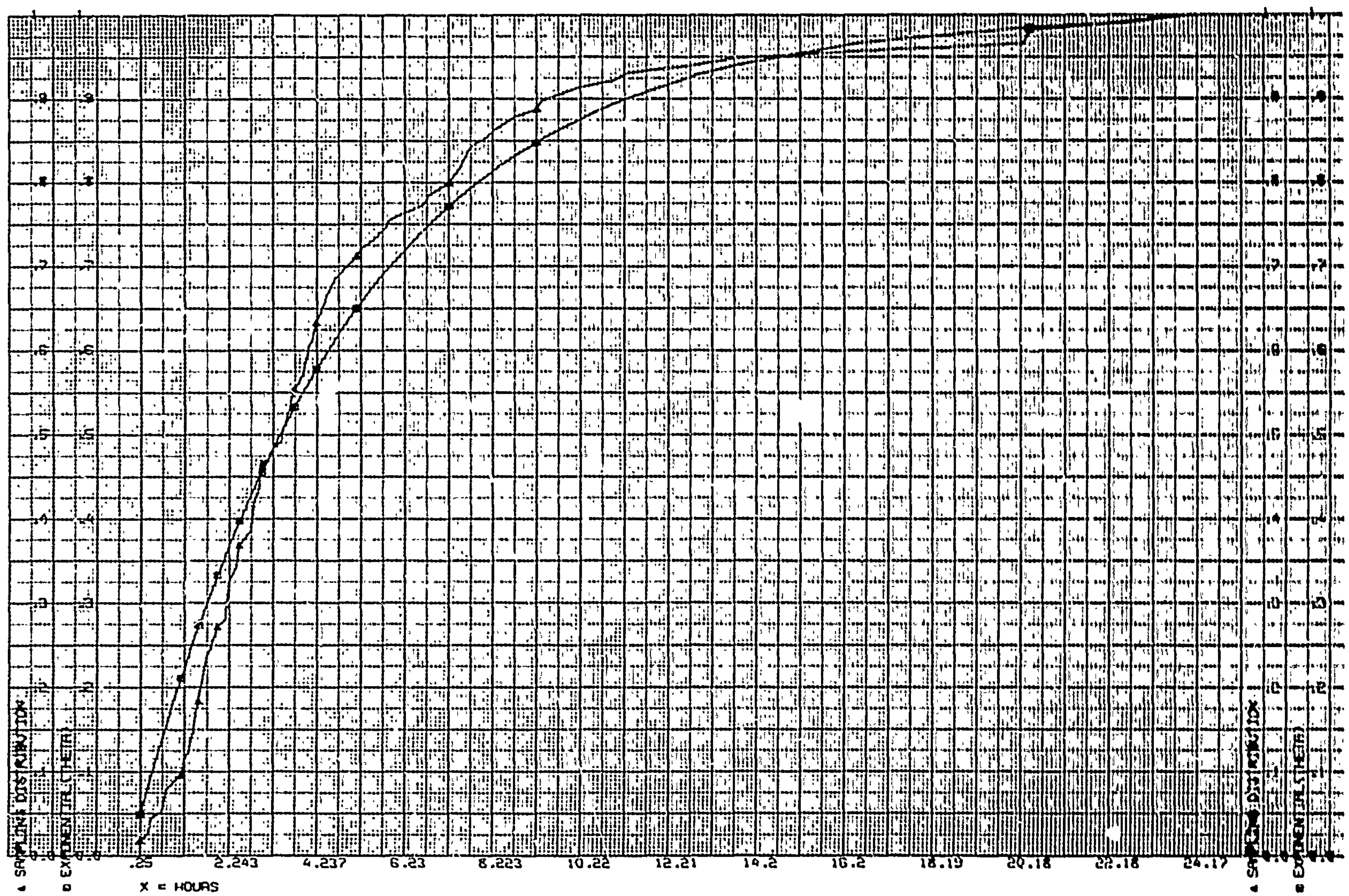

Figure 81. Test for Exponential Data: All Critical LRU's Combined - Line Active Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

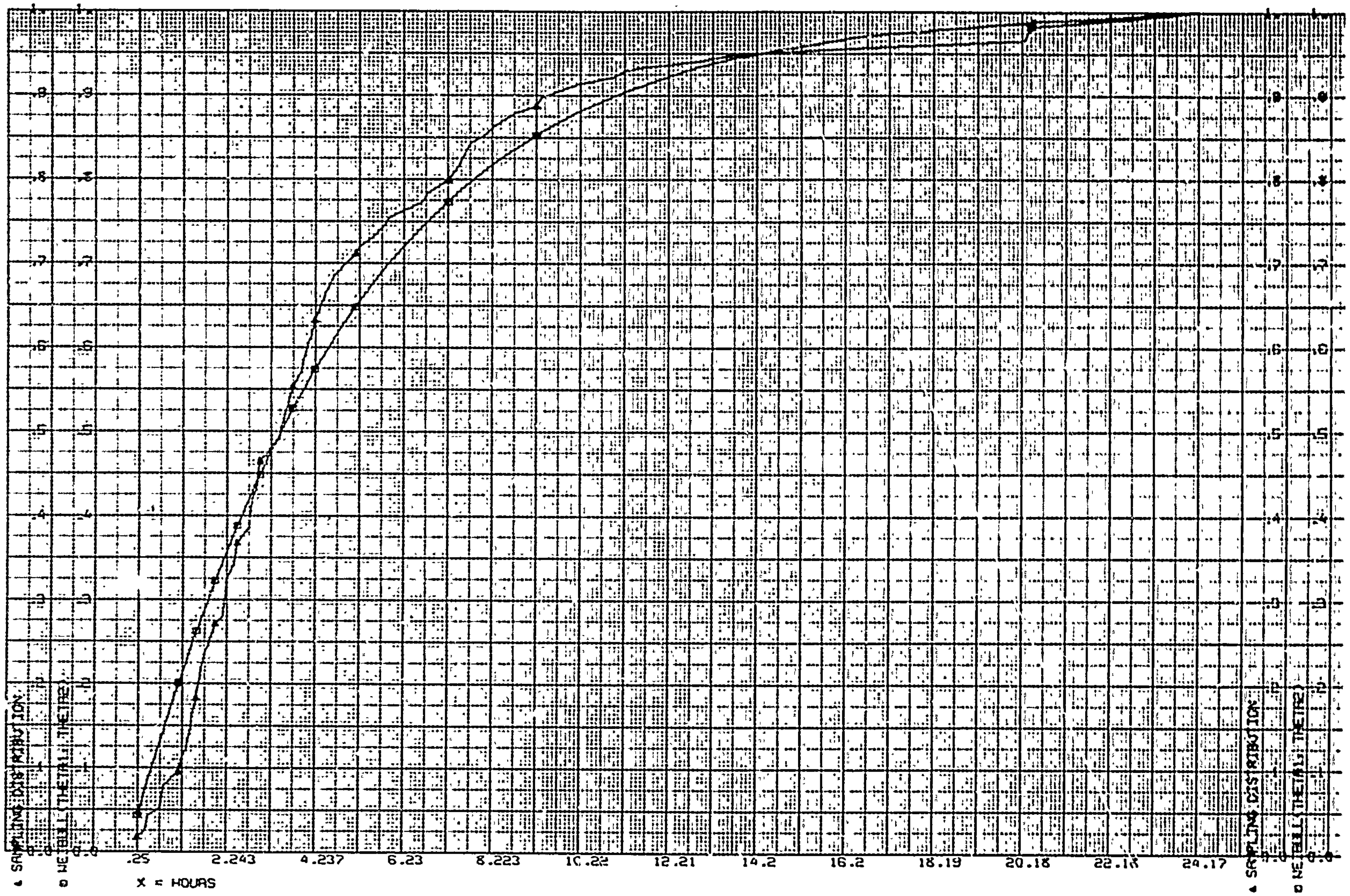

Figure 82. Test for Weibull Data: All Critical LRU's Combined - Line Active Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

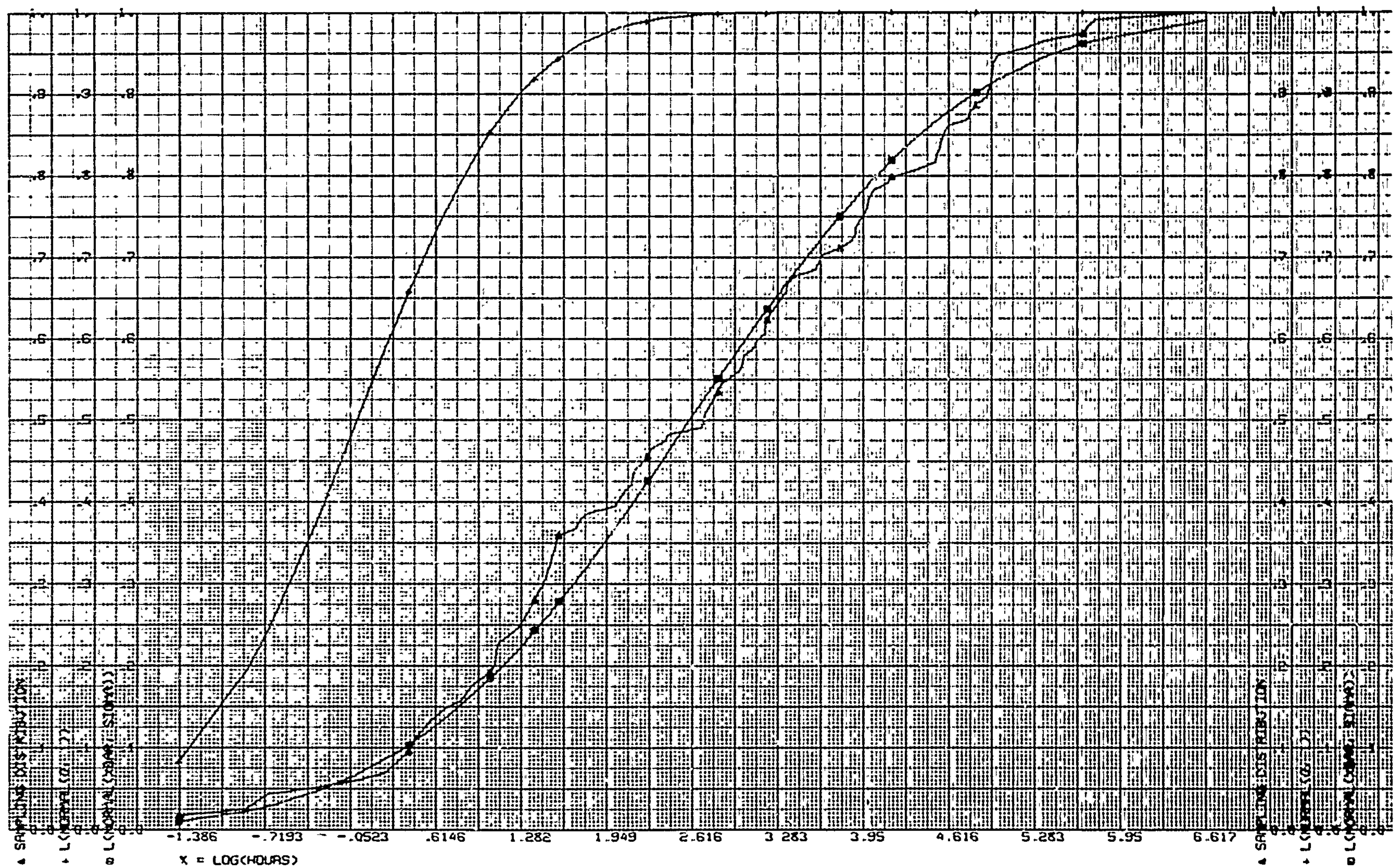

Figure 83. Test for Log Normality: All Critical LRU's Combined - Line Elapsed Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

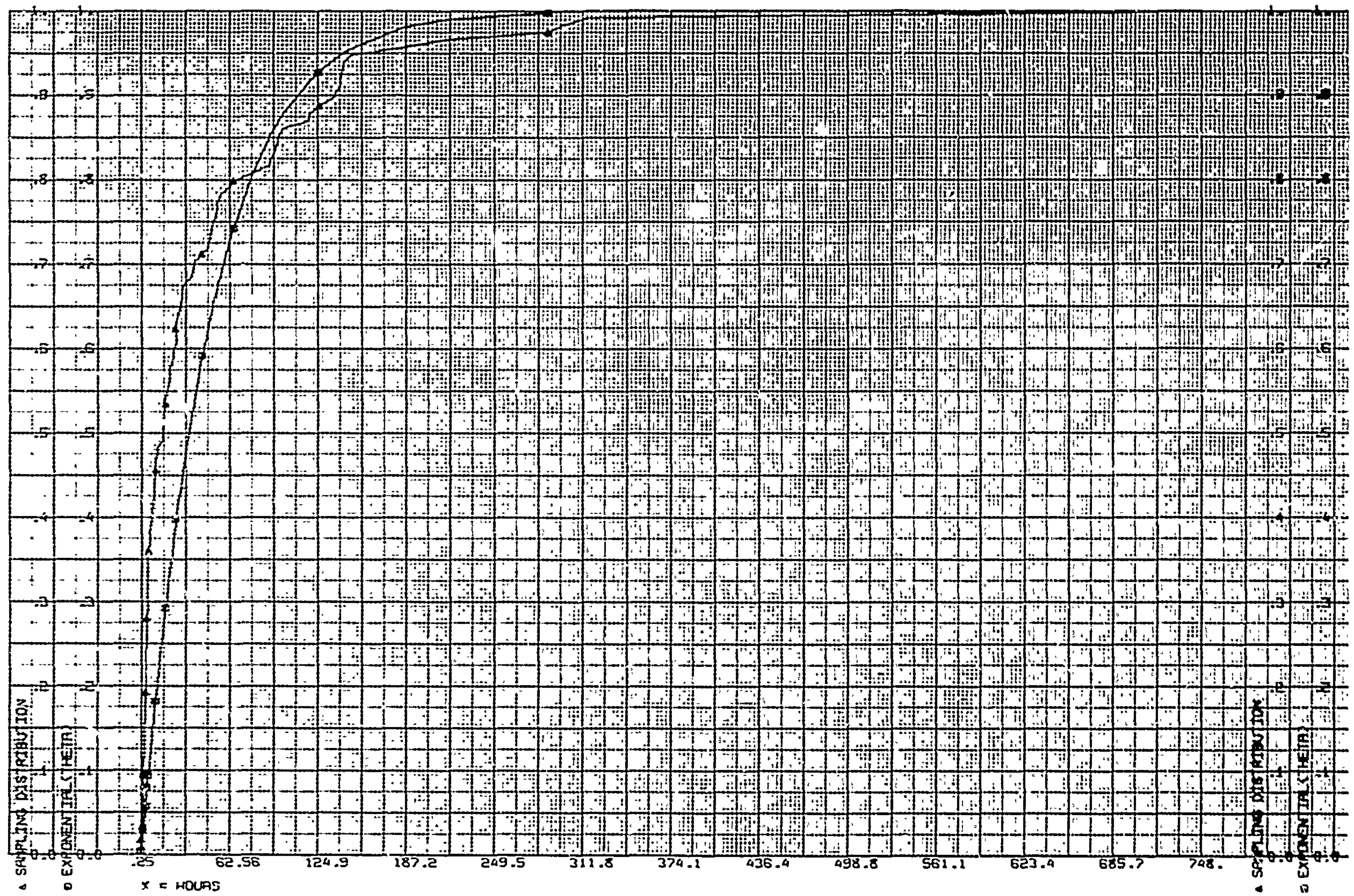

Figure 84. Test for Exponential Data: All Critical LRU's Combined - Line Elapsed Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

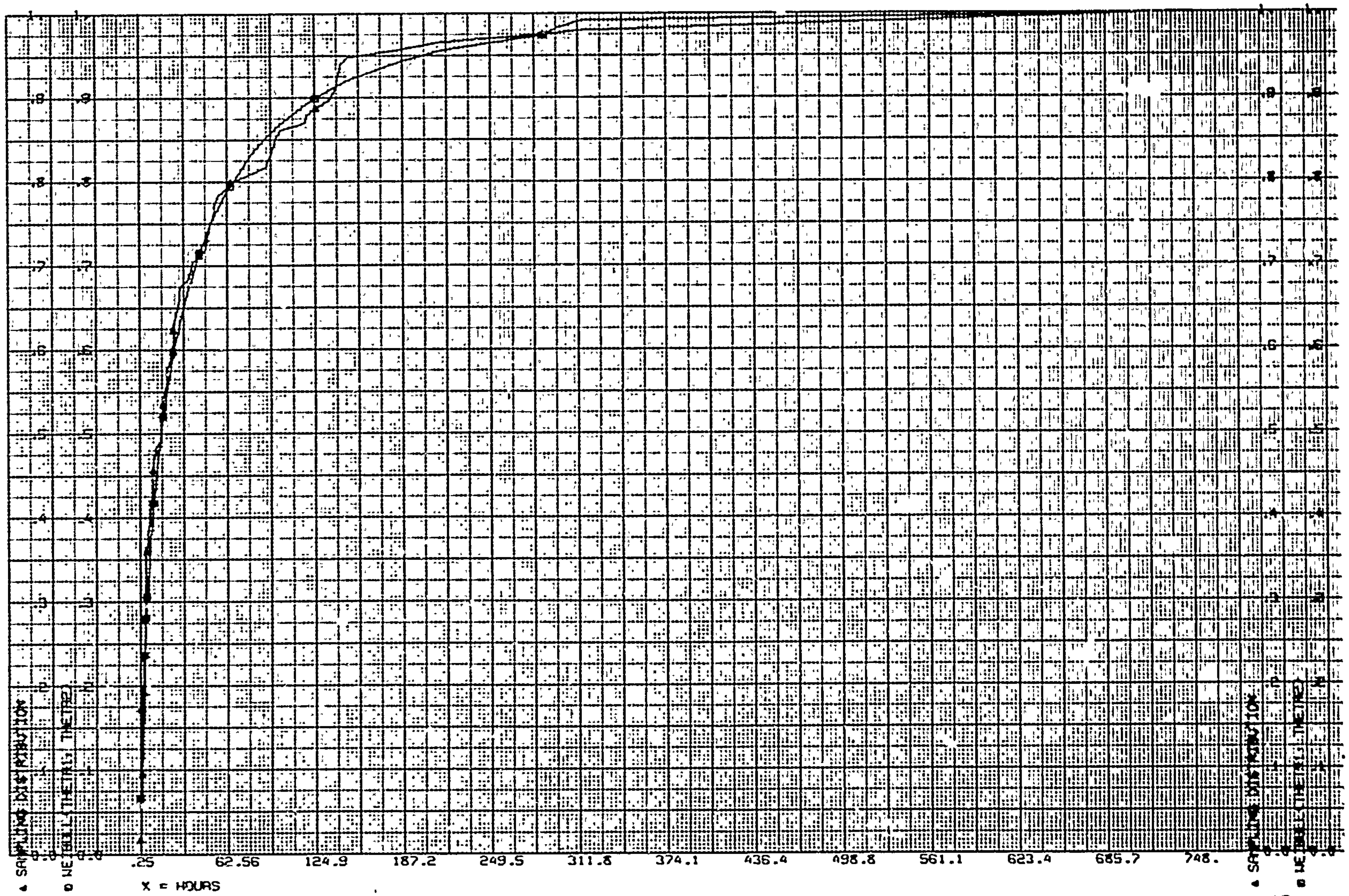

Figure 85. Test for Weibull Data: All Critical LRU's Combined Line Elapsed Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

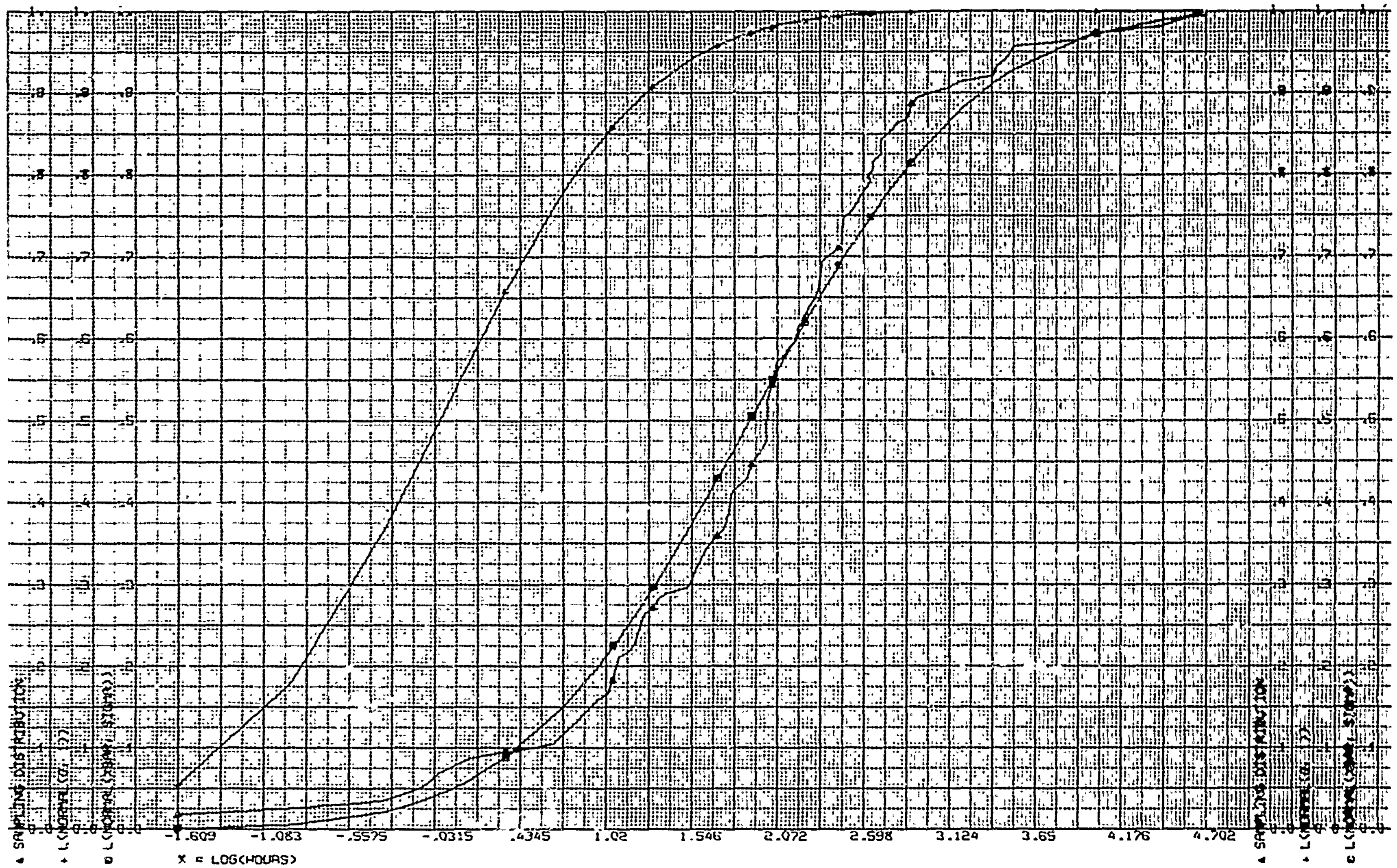

Figure 86. Test for Log Normality: All Critical LRU's Combined - Line Man Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

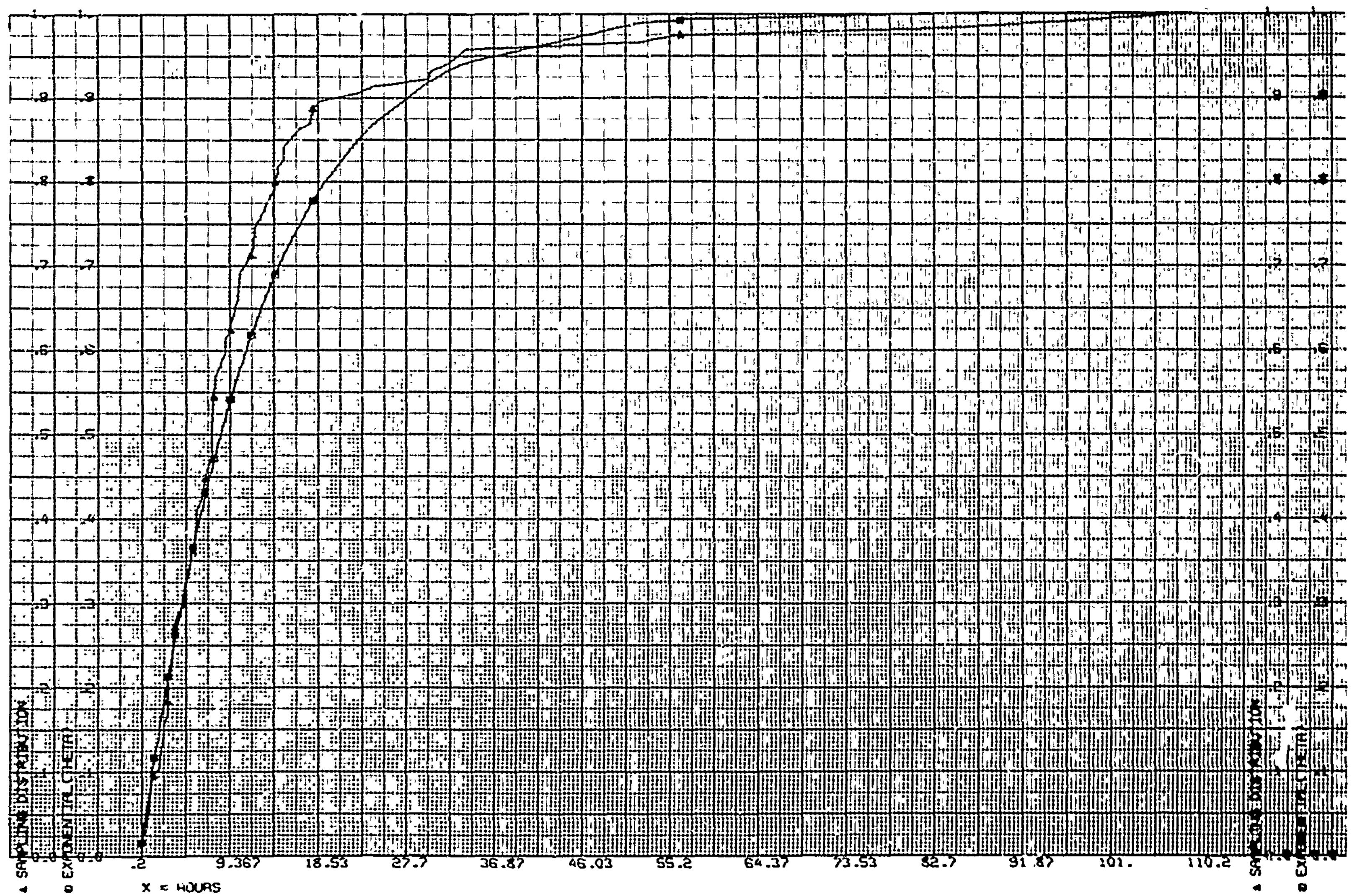

Figure 87. Test for Exponential Data: All Critical LRU's Combined - Line Man Hours, LRU'sWUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

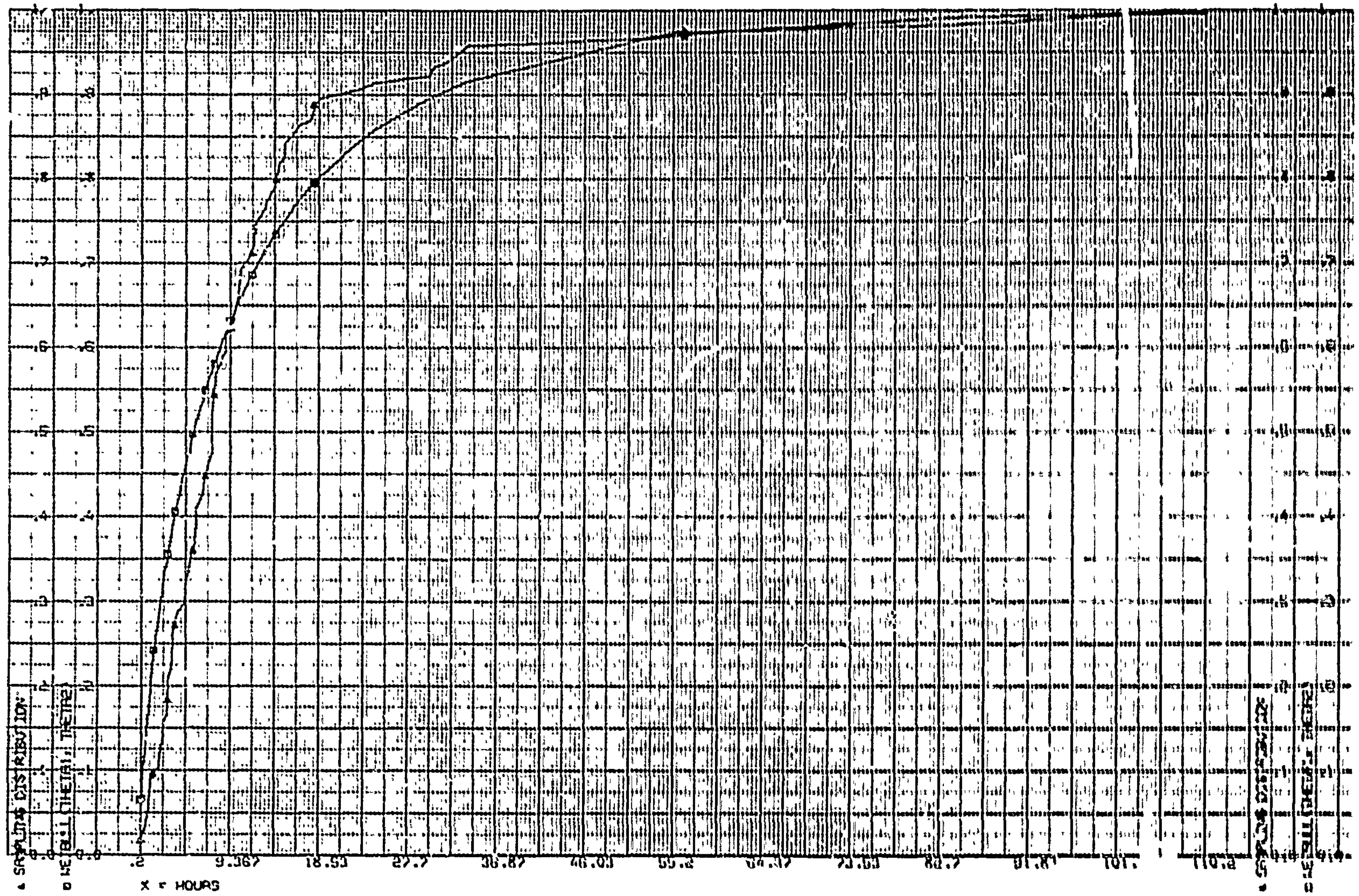

Figure 88. Test for Weibull Data: All Critical LRU's Combined - Line Man Hours, LRU's WUC 52BBR, WUC 52ADA and WUC 73ABO Not Included

APPENDIX II

PART II

DATA PROCESSING REQUIREMENTS FOR CRITICAL LRU MAINTENANCE EVENTS DATA

0.0 SUMMARY

The data processing requirements for the determination of the most likely probability distribution for maintenance events for each Critical LRU identified in Section 5.1 can be divided into two phases:

(1) Retrieval and formatting of Critical LRU maintenance events

(2) The calculation of the sample and theoretical distributions from these data.

The results and the analytical considerations for (2) are given in Part I of this appendix. In this part of Appendix II the data processing considerations are given.

1.0 RETRIEVAL AND FORMATTING OF CRITICAL LRU MAINTENANCE EVENTS

The data processing requirements for maintenance events were accomplished by analyzing all Critical LRU failure indications retrieved from the 258 data base in order to determine the original report numbers (ORN) which identified the Critical LRU maintenance events.

The following routine was used to retrieve and format the Critical LRU maintenance data needed for the analysis in Part I of this appendix.

(1) Select specific original report numbers.

(2) Sort retrieved items by original report number.

(3) Output the following two records for each Critical LRU.

(a) HEADER cols. 1-6 (blanks through col. 48)

(b) Critical LRU identifier cols. 1-48 (variable)

(4) Output the following record for each report:

ORIGINAL REPORT NUMBER (OPN)	COLS. 1 - 6
REPORT DATE (Year/Month/Day)	COLS. 7 - 12
TOTAL MAINTENANCE HOURS	COLS. 35 - 39
LOCATION (Line or Shop)	COLS. 40 - 43

(5) Output the following record for each maintenance entry entered on the report

ORIGINAL REPORT NUMBER (ORN)	COLS. 1 - 6
REPORT DATE (Year/Month/Day)	COLS. 7 - 12
START TIME	COLS. 13 - 16
STOP TIME	COLS. 17 - 20
DELAY CODE	COLS. 21 - 23
START TIME	COLS. 24 - 27
STOP TIME	COLS. 28 - 31
DELAY CODE	COLS. 32 - 34
LOCATION (Line or Shop)	COLS. 40 - 43

(6) Output the following as the final record

ENDFIL	COLS. 1 - 6

APPENDIX II

PART II

2.0 THE CALCULATIONS OF TIME ASSOCIATED WITH CRITICAL LRU MAINTENANCE EVENTS

The computer program used to summarize the maintenance events data retrieved from the F-111 Category II data base by FFS is described below.

ACTIVE HOURS PROGRAM

This program takes data in the form of punched cards from the retrieval procedure mentioned in Section 1.0 above. In general, this program computes active hours, elapsed hours, and man hours (subdivided by shop and line) for each original report number. The procedure is as follows: original report numbers are grouped into several Critical LRU categories and sorted within a categrory by report number. For identification purposes a title card is generated for each original report number. Generally, the main program reads a Critical LRU title card, then summarizes all data from each original report number sequence for that LRU. The active hour data is stored in an array subdivided according to line and shop and man hours data are treated in a similar manner. When all data for a given report number is summarized, Subroutine ACTCAL is called to do the actual active hours computation, then upon returning to the main program a single line of output is printed and punched for that report number. In addition to the ACTCAL routine, SORT and TIME 7 are also used. SORT is used by ACTCAL to sort the start/stop times by start time. TIME 7 is used by the main program to convert all time to hours since 1 January 1966.

DESCRIPTION OF THE INPUT DATA

The input to this program is the following punched card deck.

(1) HEADER CARD — Containing the work HEADER punched in columns 1 - 6. A HEADER CARD must be immediately followed by a TITLE CARD

(2)	TITLE CARD	Containing a Critical LRU title punched in columns 1-48.
(3)	DATA CARD	Containing an original report number (ORN) in columns 1-16. A date of the form (year/month/day) in columns 7 - 12, A start time in 13 - 16, A stop time in 17 - 20, A three character alpha field in 21 - 23, A start time in 24 - 27, A stop time in 28 - 31, A three character alpha field in columns 32 - 34, A man-hours value in columns 35 - 39, The work LINE or SHOP in columns 40 - 43.

Here the DATA Cards for a particular Critical LRU must be sorted by original report number.

(4)	TERMINATOR CARD	Containing the word ENDFIL in column 1 - 6. This must be the last card of the data deck.

A TYPICAL DATA DECK MIGHT LOOK AS FOLLOWS:

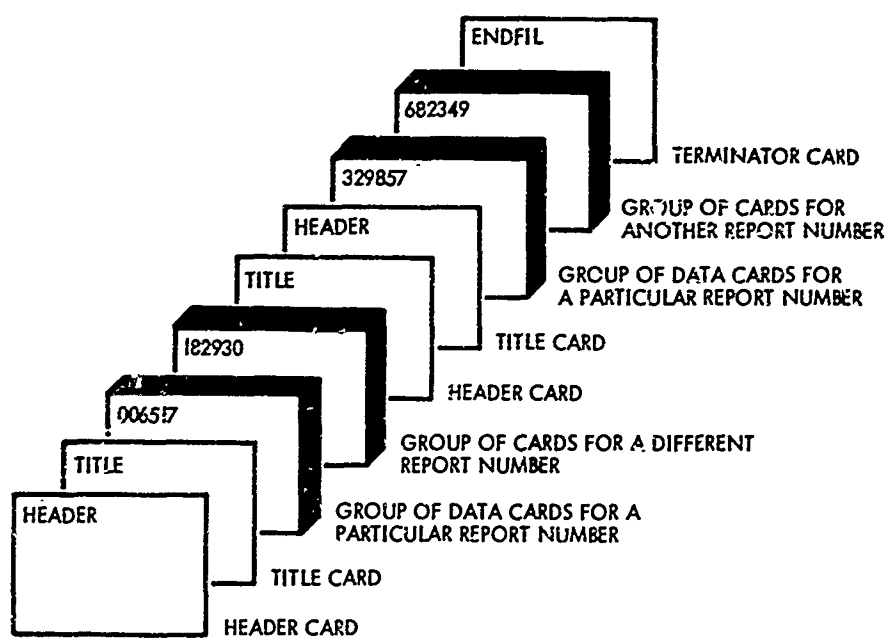

Figure 2.1: A typical data deck setup for the Active Hours Program.

LIMITATIONS

No more than 500 start/stop time pairs will be accepted for LINE or SHOP. Moveover, any data card that does not contain the words LINE or SHOP in columns 40 - 43 will be ignored. In addition, there are two sets of start/stop times on each data card. Each time pair is followed by a three character tag field. If this tag field contains the letter T (left justified) then the associated start/stop time is ignored.

DESCRIPTION OF KEY VARIABLES

IHDR	Critical LRU title
INUMT	Current original report number
LINECT	Output line counter
XMANHR (1), XMANHR (2)	Accumulated man-hours for shop and line
JK (1), JK (2)	Total number of active-hour start/stop time pairs for shop and line
T(I, 1, 1), T(I, 2, 1)	Start/stop time pair (shop)
T(I, 1, 2), T(I, 2, 2)	Start/stop time pair (line)
ACTHR1, ACTHR2	Total active hours for shop and line
ELHR1, ELHR2	Total elapsed hours for shop and line

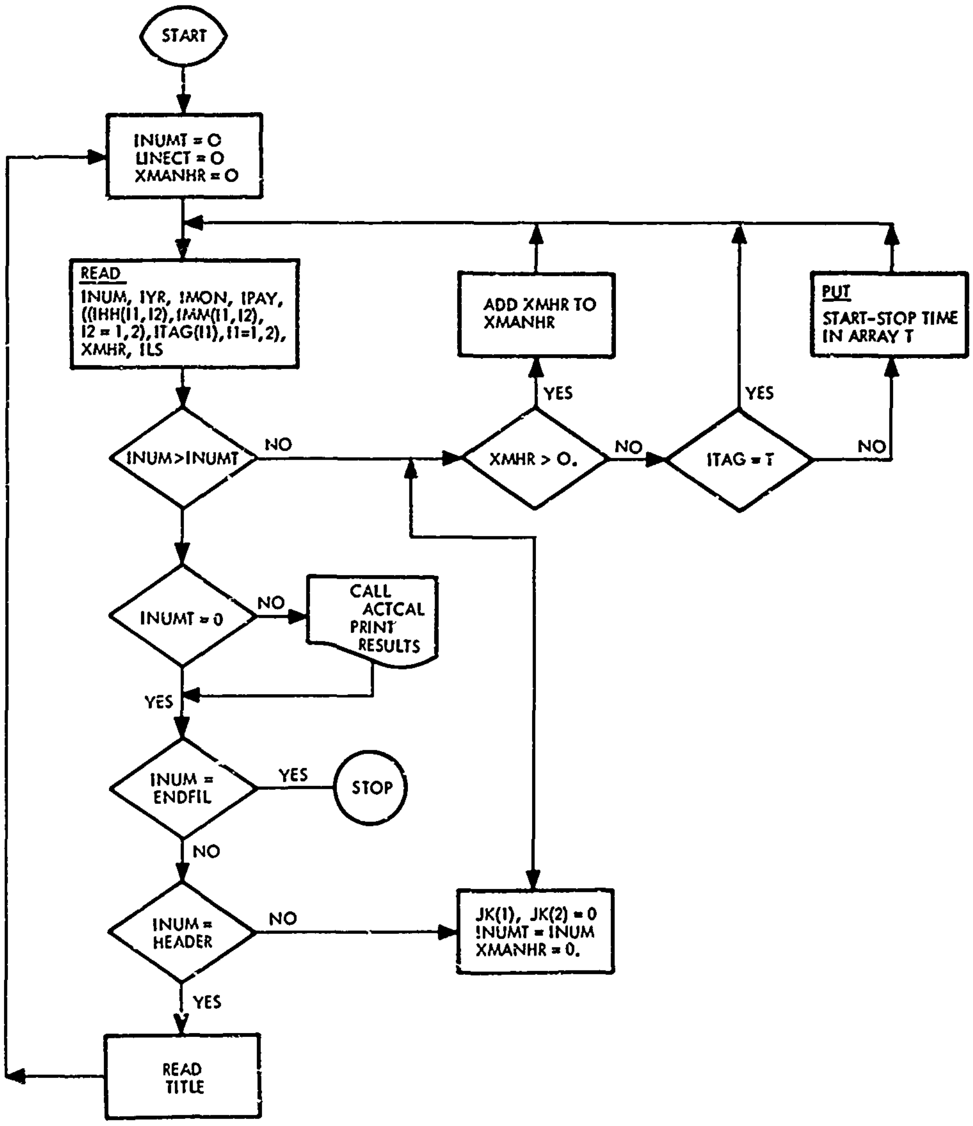

Figure 2.2: Flow Chart of the Main Routine in the Active Hours Program

SUBROUTINE ACTCAL

The start/stop time pairs are sorted by start time in this routine. Then for each start time the latest stop time is found and if this time does not overlap the next time interval, this time period is added to the accumulated sum. If the next interval is contained in this time period, the next interval is ignored. Otherwise, an overlap occurs and the first interval is modified to reflect this overlap.

DESCRIPTION OF KEY VARIABLES

T (500, 2)	Array contains start/stop times
IMAX	Number of start/stop pairs
ACTHRS	Total active hours
ELHRS	Total elapsed hours

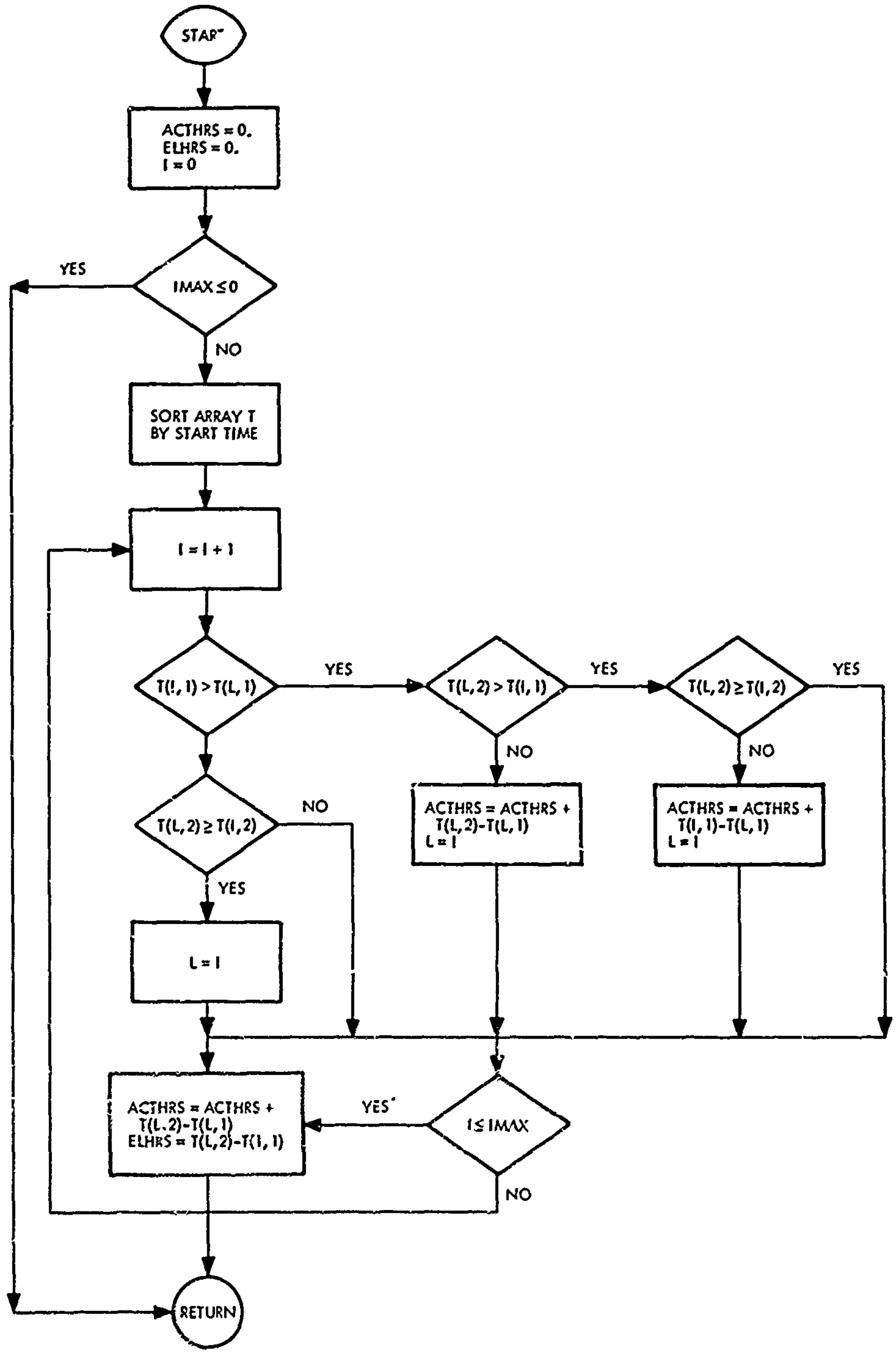

Figure 2.3: Flow Chart of ACTCAL in the Active Hours Program.

APPENDIX III

DATA PROCESSING REQUIREMENTS FOR REPLACEMENTS AND FAILURE INDICATIONS

0.0 SUMMARY

The derivation of the mathematical relationship between failure indications and replacements can be partitioned into the areas of processing:

(1) Retrieval of failure indications from the 258 data base and the determination of whether a line or shop replacement occurred.

(2) The calculation of the regression of replacements per unit time on failure indications per unit time for each critical LRU.

In this appendix the data processing requirements for problem (2) of Section 5.0 are given.

1.0 THE DEFINITION OF FAILURE INDICATION AND REPLACEMENT

The following definitions form the basis for the algorithm used in the computer programs described in this appendix. A failure indication is defined as a maintenance event with an "Action Taken" Code (ACTAK) of P, R, S, F, G, K, L, V or Z (Table 4.2.1) and a "How Malfunction" Code (HOW MAL) that is not a "No Defect" Code (Table 4.3.2). On the other hand, a line level replacement occurs when a piece of hardware is removed and replaced by a like piece of hardware with a different part number P/N and serial number S/N. This occurs if the "ACTAK" of the failure indication is of the R, P or Q type and the maintenance event directly related to the P has a different P/N and S/N. Generally, a line level replacement does not occur when the ACTAK of the failure indication is S, F, G, K, L, V or Z, or if the P and the associated Q ACTAK have the same P/N and S/N.

Similar to the above a shop level replacement occurs when a piece of hardware is removed as a result of a failure indication, i.e., if the ACTAK of the failure indication is a R or P and the piece of hardware is

condemned at the shop level or shipped off base for repair. Obviously, a shop level replacement does not occur if the piece of hardware removed as a result of a P or R ACTAK failure indication is rendered serviceable in the shop.

2.0 THE ALGORITHM

The algorithm used is the following:

(I) Retrieve failure indication data

(II) Retrieve data necessary to determine replacement status of each failure indication.

(III) Determine replacement status of each failure indication. This falls into the following categories:

(1) Line

(a) Replacement occurred

(b) Replacement did not occur

(c) Status unknown

(2) Shop

(a) Replacement occurred

(b) Replacement did not occur

(c) Status unknown

(IV) Generate class intervals in calendar time (time of occurance for each failure indication) for each aircraft and calculate the number of failure indications and replacements per class interval and output the results in a format suitable for regression analysis.

The only portion of the algorithm which posed implementation problems was that of handling failure indications where the replacement status was unknown through incomplete or incorrect reporting. These events could either be replacement or no replacement events. If these events are considered to be replacement events, a higher level of replacements than actually occurred are observed, i.e., "a worse case spares requirements." On the other hand, if these events are considered not to be replacement events, a lower level of replacement than actually occurred are observed, i.e., "a least case spares requirement." The

worse and least case assumptions give an upper and lower bound for the relationship between replacements and failure indications with the true relationship lying between these two extremes. The distance between these bounds serves as an excellent measure of the quality of the data and the accuracy of the results obtained from these data. The manner in which this was handled is summarized below.

The data retrieval and reduction task described earlier was broken into three sections for programming efficiency. In the first section, the failure indications and events necessary to determine its replacement status were retrieved and formatted using FFS. The exact selection criteria and output formats are below. The second and third sections were programmed separately but executed on the computer as one job. In the second section, the replacement status of a failure indication is determined. Since there are two cases to be considered, for both shop and line, four versions of the routine which determine replacement status were developed. The four routines and their respective functions are the following:

(1) MATCH - Carries out line level processing assuming "no replacement" in doubtful cases

(2) MATCH2 - Same as MATCH for shop level processing

(3) MATCH3 - Carries out line level processing assuming "replacement" in doubtful cases.

(4) MATCH4 - Same as MATCH3 for shop level processing

These routines accept data retrieved and formatted by FFS and output these data in a format for additional processing.

The matched data from the above routines are processed by a series of sorts and routines to produce the number of replacements and failure indications for a given time class interval. These data are separated by Critical LRU and the aircraft in which it was installed.

3.0 FSS PROCESSING

The retrieval and formatting of the data was accomplished through FFS. The specifications are the following:

(I) Select line actions which satisfy either of the following criteria:

(1) Action taken code equal to F, G, K, L, P, R, S, V, Z. And how malfunction code not equal to 793, 797, 798, 799, 800, 801, 802, 811, 812.

(2) Action taken code equal to Q.

(II) From the line items that satisfy either of the above criteria select, by work unit code, each Critical LRU and perform the following selective output actions:

(1) If the action taken code is P, S, F, G, K, L, V or Z output the following record:

CRITICAL LRU Number	COLS. 1-4
AIRCRAFT SERIAL Number	COLS. 5-14
ORIGINAL REPORT Number	COLS. 15-20
FAILED LRU PART Number	COLS. 21-35
FAILED LRU SERIAL Number	COLS. 36-45
ACTION TAKEN CODE	COL. 46
DISCOVERED DATE AND TIME	COLS. 47-56
HOW MALFUNCTIONED CODE	COLS. 67-69
WORK UNIT CODE	COLS. 70-77
CONSTANT ZERO	COL. 78

(2) If the action taken code is Q output the following record:

CRITICAL LRU Number	COLS. 1-4
AIRCRAFT SERIAL Number	COLS. 5-14
ORIGINAL REPORT Number	COLS. 15-20
INSTALLED LRU PART Number	COLS. 21-35
INSTALLED LRU SERIAL Number	COLS. 36-45
ACTION TAKEN CODE	COL. 46
DISCOVERED DATE AND TIME	COLS. 47-56
REPORT DATE	COLS. 57-62
HOW MALFUNCTIONED CODE	COLS. 67-69
WORK UNIT CODE	COLS. 70-77
CONSTANT ZERO	COL. 78

(3) If the action taken code is R output the following record:

CRITICAL LRU Number	COLS. 1-4
AIRCRAFT SERIAL Number	COLS. 5-14
ORIGINAL REPORT Number	COLS. 15-20
FAILED LRU PART Number	COLS. 21-35
FAILED LRU SERIAL Number	COLS. 36-45
ACTION TAKEN CODE	COL. 46
DISCOVERED DATE AND TIME	COLS. 47-56
REPORT DATE	COLS. 57-62
HOW MALFUNCTIONED CODE	COLS. 67-69
WORK UNIT CODE	COLS. 70-77
CONSTANT ZERO	COL. 78

(III) Select shop actions which have one of the following action taken codes:

A, B, F, G, H, J, K, L, N, R, S, V, X, Z

(IV) From the line items that satisfy the above criteria select, by work unit code, each critical LRU and output a record in the format of (3) under II above with a constant ONE in COL. 78.

(V) Output the following as the final record:

((((	COLS. 1-4
((((((	COLS. 15-20

The manner in which these specifications were applied varied according to which Critical LRU was being considered and to which routine these data were to serve as input.

4.0 PROCESSING THE DATA FROM FFS

The general processing procedure is outlined in Figure 4.1.

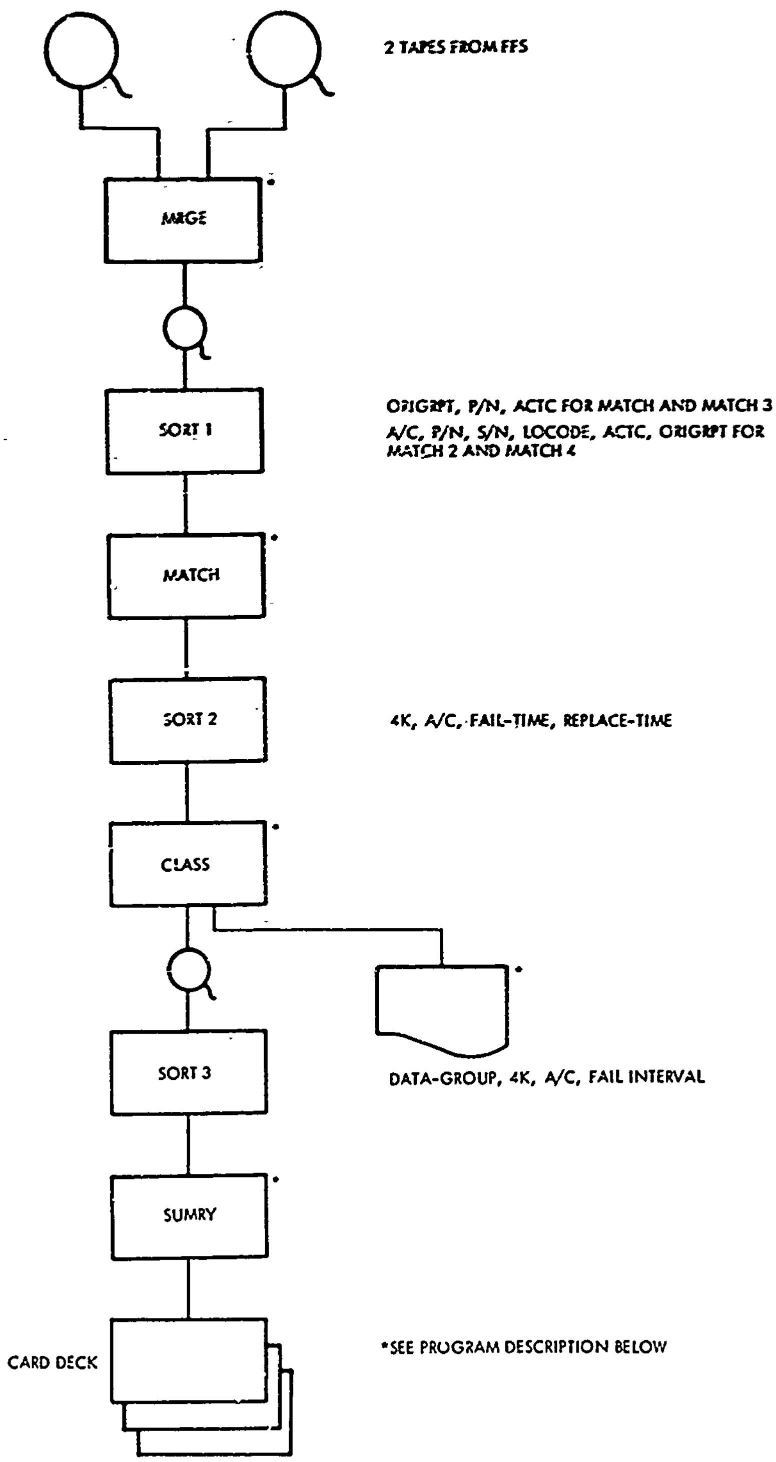

Figure 4.1: General Flow Chart of the Data Processing Requirements

If files between steps are not indicated as tapes, they are on inter-system reserve units (disk). The input to MRGE (Figure 4.1) has the following format:

COL.	1-4	4K-NUMBER
	5-14	AIRCRAFT-NUMBER (A/C)
	15-20	ORIGINAL REPORT NUMBER
	21-35	PART-NUMBER
	36-45	SERIAL-NUMBER
	46	ACTAK
	47-56	FAIL TIME
	57-66	REPLACE TIME
	67-69	HOW MAL
	70-77	WORK UNIT CODE (WUC)
	78	LINE OR SHOP CODE (0 or 1) - MATCH2 and MATCH4 only
	79-84	BLANKS

The last record on each tape is as follows:

COL.	1-4	'(((('
	5-14	blanks
	15-20	'(((((('
	21-84	BLANKS

The input to MATCH (Figure 4.1) is the same as the input to MRGE. On the other hand, the input to CLASS is the following:

(1) Control cards (between a $DATA card and a $EOF card, following CLASS), indicating calendar hour class intervals:

COL.	1-6	Interval in hours, right justified
	7-80	blank

Last control card:

COL.	1-6	'999999'
	7-80	blanks

(2) File from any MATCH program, sorted on 4K, A/C, FAIL-TIME, REPLACE-TIME:

COL.	1-4	4K-NUMBER
	5-8	A/C (last 4 characters)
	9-18	FAIL TIME
	19-28	REPLACE TIME
	29-84	BLANKS

Dummy EOF, last record on tape:

COL.	1-4	'(((('
	5-14	BLANKS
	15-34	ZEROS
	35-84	BLANKS

Similar to (2) above for CLASS the input to SUMRY must be sorted on DATA-GROUP, 4K, AIRCRAFT (A/C) FAIL-INTERVAL. The input format is the following:

COL.	1-2	Indicates to which DATA-GROUP data belongs (01, 02, . . .)
	3-6	4K-NUMBER
	7-10	A/C-NUMBER
	11-16	FAIL INTERVAL
	17-22	FAIL COUNT
	23-28	REPLACE INTERVAL
	29-34	REPLACE COUNT
	35-84	BLANKS

One card preceding the data for each calendar hour interval with the following format is required.

COL.	1-2	Same as above (increases by one for each of these cards)
	3-8	CALENDAR HOUR INTERVAL
	9-84	BLANKS

PROGRAM DESCRIPTION

MRGE places every record from each of the two tapes generated by FFS retrieval on to a single file.

SORT1 sorts the file created by MRGE. Scientific collating sequence is used. The sort for data into MATCH or MATCH3 is: ORIGINAL-REPORT-NUMBER, PART-NUMBER, and ACTION-TAKEN CODE. The sort for data into MATCH2 or MATCH4 is: AIRCRAFT-NUMBER, PART-NUMBER, SERIAL-NUMBER, LOCATION-CODE (line or shop), ACTION-TAKEN CODE and ORIGINAL-REPORT.

MATCH attempts to match line P and Q actions (remove and install) to determine if a spares requirement is generated. Other action codes are passed on to CLASS unaltered.

DESCRIPTION OF KEY VARIABLES

IBSYS, JSYS	Functional 4000-Number
ISER1, JSER2 ISER2, JSER2	Aircraft Number (A/C)
IRPT, JRPT	Original Report Number
IPTNR1, JPTNR1 IPTNR2, JPTNR2 IPTNR3, JPTNR3	Part Number
ISERL1, JSERL1 ISERL2, JSERL2	Serial Number
IACTC, JACTC	Action Taken Code
IFAIL1, FAIL1 IFAIL2, JFAIL2	Fail Time
IRPLC1, JRPLC1 IRPLC2, JRPLC2	Replace Time

The Flow Chart of MATCH is given in Figure 4.2.

MATCH2 attempts to match P and Q line actions, P or R line action with matching shop action. A restriction that matching records occur within 30 days is placed on the above. P and R orphan records are outputted as well as all other line actions. A lone Q line item and all lone shop items are ignored.

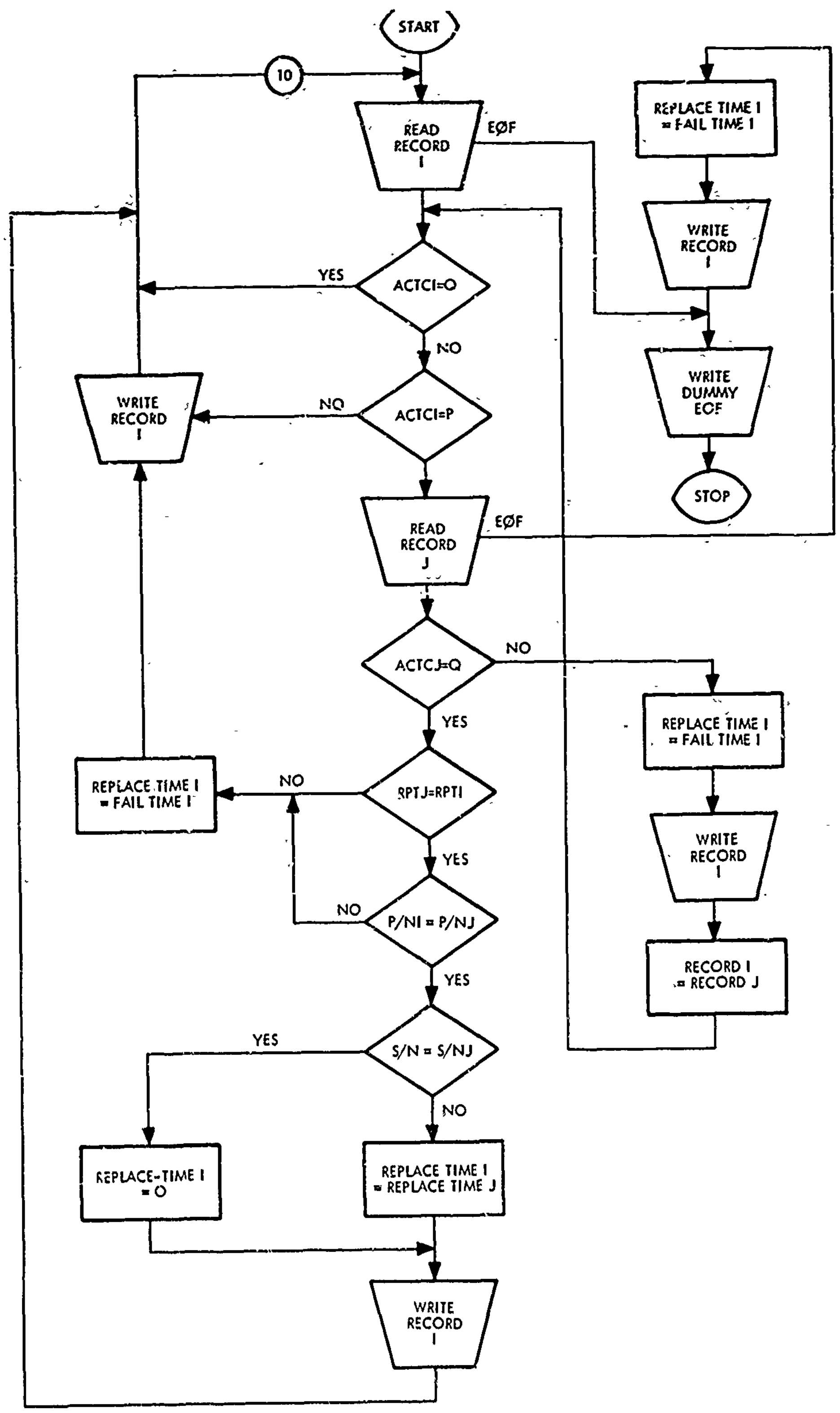

Figure 4.2: Flow Chart of MATCH

DESCRIPTION OF KEY VARIABLES

The key variables for MATCH2 are the same as MATCH with the following exceptions:

IPN1, JPN1 IPN2, JPN2 IPN3, JPN3	Part Number
ISN1, JSN1 ISN2, JSN2	Serial Number
IYRF, JYRF IMONF, JMONF IDAYF, JDAYF IHRF, JHRF IMINF, JMINF	Fail Time
IYRR, JYRR IMONR, JMONR IDAYR, JDAYR IHRR, JHRR IMINR, JMINR	Replace Time
LCODE, FLOCOD	Line or Shop Location Code

The Flow Chart of MATCH2 is given in Figure 4.3.

MATCH3 is used to match P and Q actions. When MATCH encountered doubtful matches, it assumed no spares requirement. MATCH3, on the other hand, assumes a spares requirement is generated by doubtful matches, in effect, worse case spares generation.

DESCRIPTION OF KEY VARIABLES

The key variables for MATCH3 are the same as those for MATCH. The Flow Chart of MATCH3 is given in Figure 4.4.

MATCH4 associates P, Q and R line actions with shop actions that are consequently generated. MATCH4 assumes worse case conditions, i.e., a requirement for spares has been generated in all doubtful cases. Finally no time restrictions are observed on associated line and shop actions in MATCH4.

DESCRIPTION OF KEY VARIABLES

The key variables of MATCH4 are the same as those for MATCH2. The Flow Chart of MATCH4 is given in Figure 4.5.

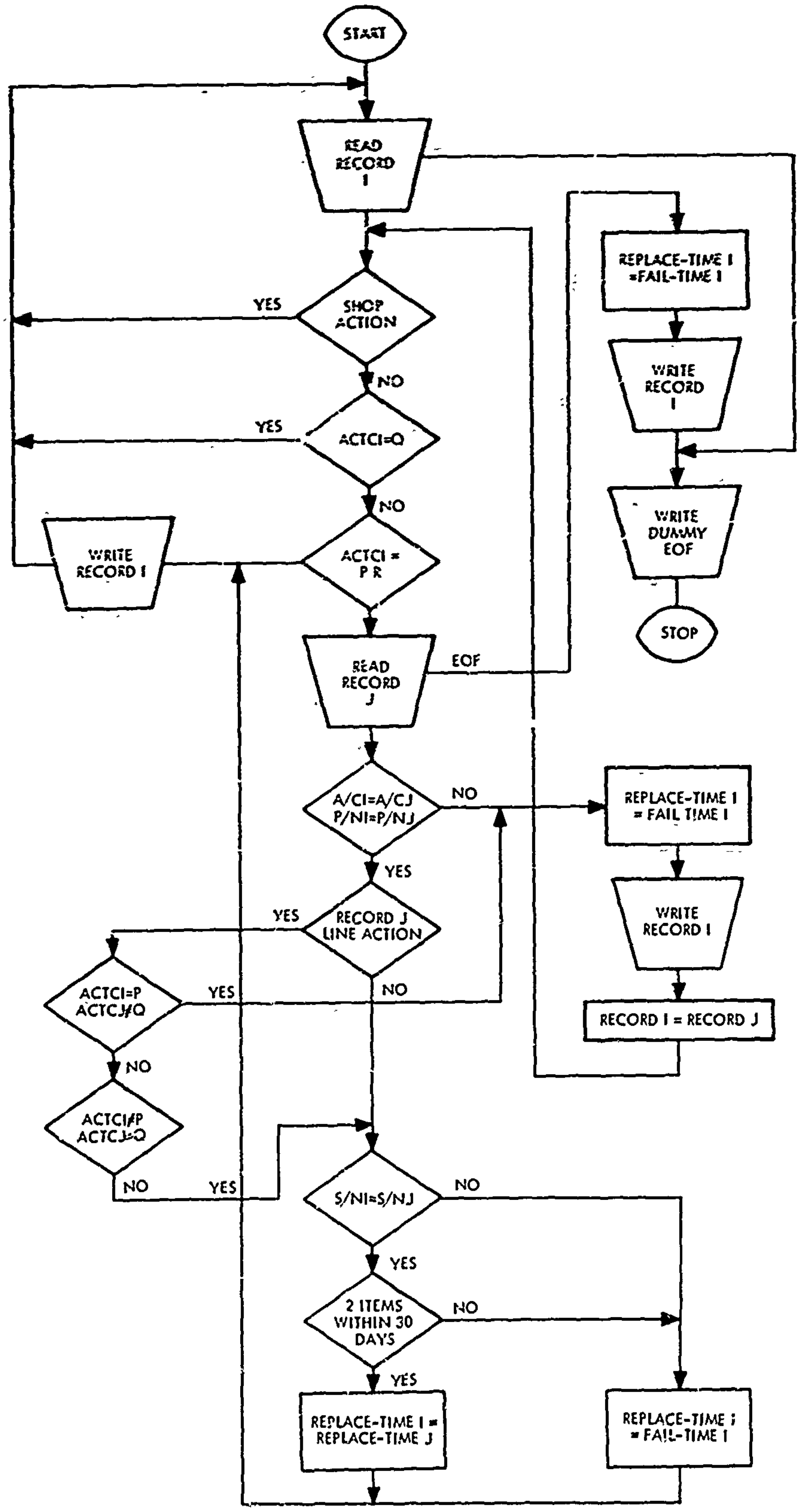

Figure 4.3: Flow Chart of MATCH2

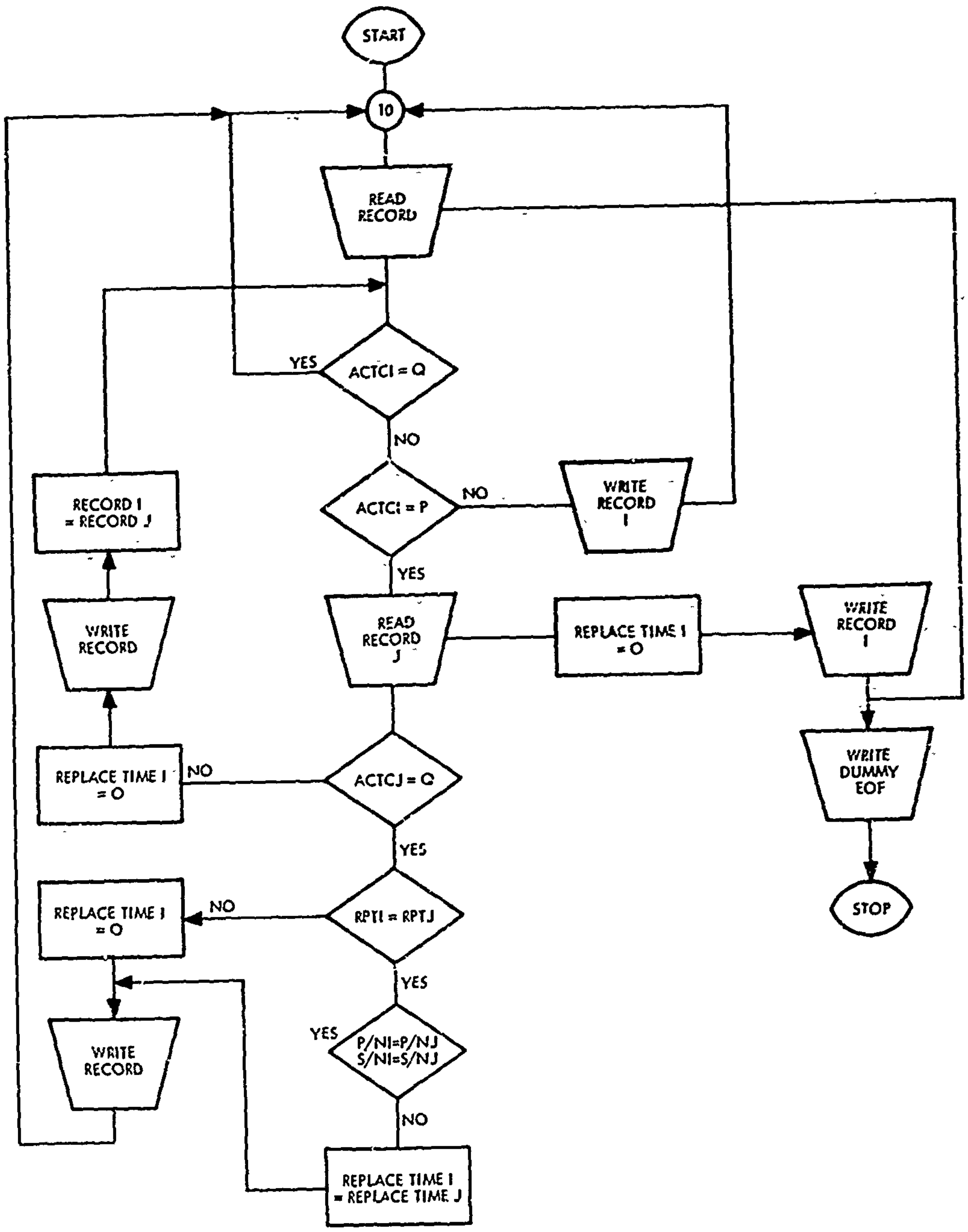

Figure 4.4: Flow Chart of MATCH3

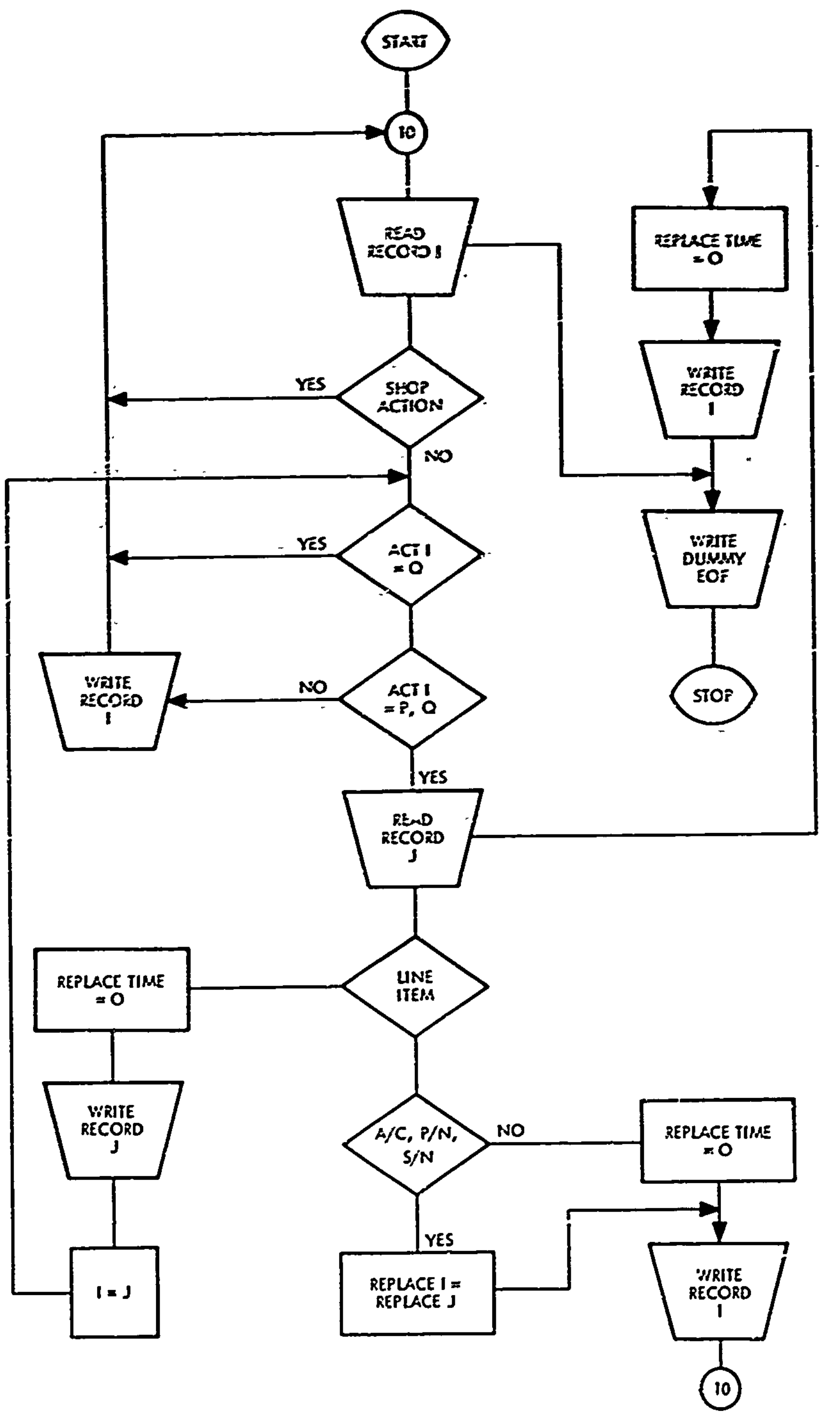

Figure 4.5: Flow Chart of MATCH4

SORT2 sorts the output of MATCH, 2, 3, and 4 using scientific collating sequence, on 4K-NUMBER, A/C-NUMBER, FAIL-TIME, REPLACE-TIME.

CLASS reads one or more Calendar Hour Interval Control Cards. For each control card all the data from MATCH is read, the fail and replace interval is determined and an output record is generated whenever a break occurs on A/C-NUMBER, 4K-NUMBER, FAIL-INTERVAL, or REPLACE-INTERVAL (if no break occurs, fail and replace events are totalled within the current interval). A unique integer is attached to all data associated with each calendar hour interval to keep the data together in the sort following CLASS. In addition, a listing is printed (for each calendar hour interval) giving the number of intervals having data for each 4K-NUMBER with A/C-NUMBER, and how many of these intervals had only one data event.

CLASS calls a routine named CONV which in turn calls SPLIT. These are used to get around the automatic FORTRAN leading zero suppression on fields that are used in the following sort.

DESCRIPTION OF KEY VARIABLES

ISYS	4K-NUMBER
ISER	A/C-NUMBER
IX	Calculated Fail Interval
IV	Calculated Replace Interval
ITOTX	Points in Fail Interval
ITOTY	Points in Replace Interval
ITOTA	Number of Intervals with data for particular A/C-4K
ITOTB	Number of above with only 1 data point
ICT, ICOUNT	DATA-GROUP identifier

The Flow Chart for CLASS is given in Figure 4.6.

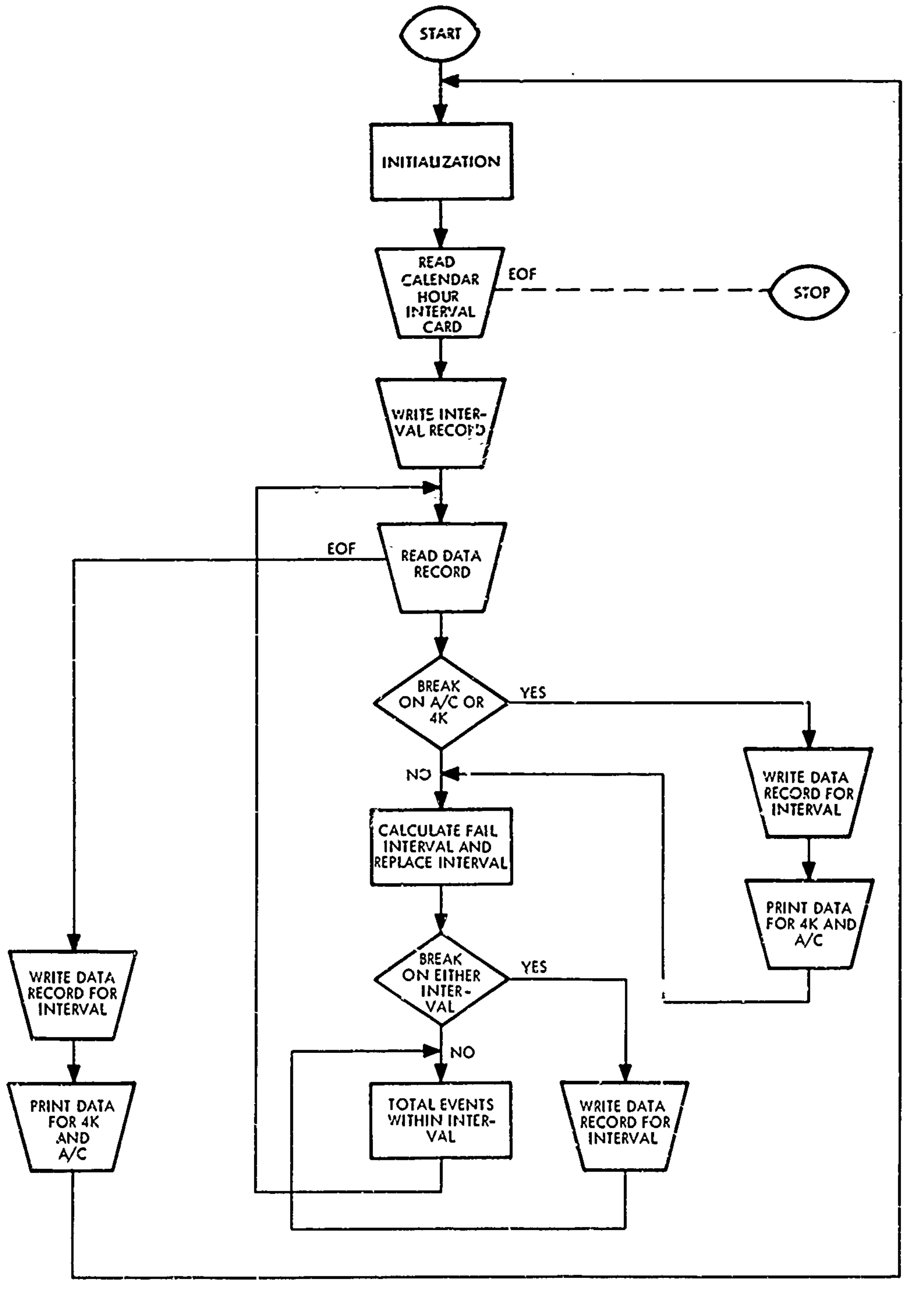

Figure 4.6: Flow Chart of CLASS

SORT3 sorts the output of CLASS on DATA-GROUP, 4K-NUMBER, A/C-NUMBER, and FAIL-INTERVAL.

SUMRY treats each data-group separately. For all records, within a data-group, for a particular 4K-NUMBER, A/C-NUMBER, and FAIL-INTERVAL, the total number of failure and replacement events is calculated and a card is punched. The deck of cards produced by SUMRY serves as input for statistical analysis. The Flow Chart of SUMRY is given in Figure 4.7.

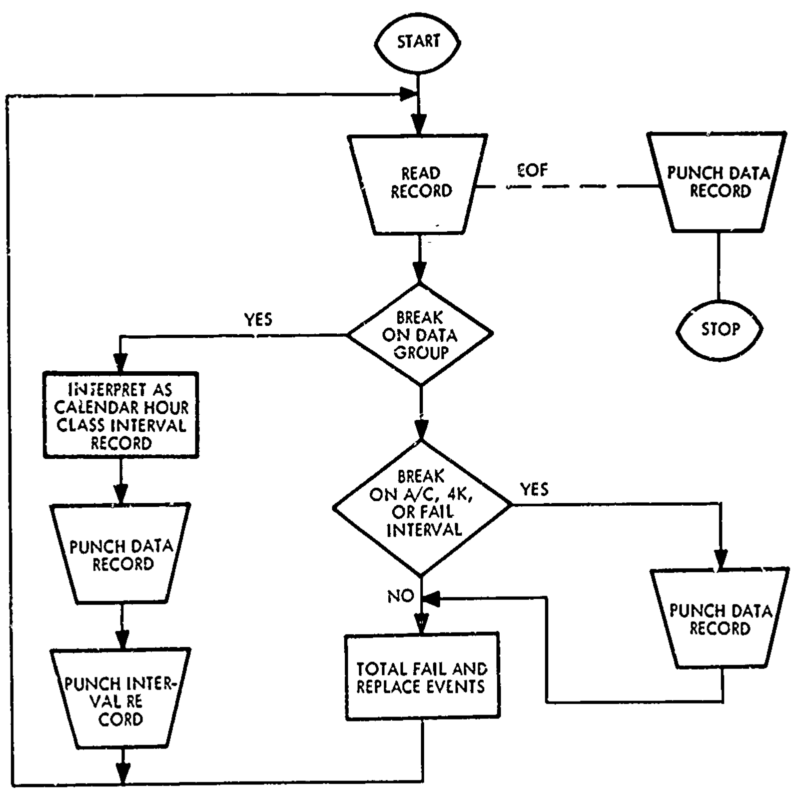

Figure 4. 7: Flow Chart of SUMRY

APPENDIX IV

DATA PROCESSING REQUIREMENTS FOR THE ESTIMATED REPLACEMENTS PER MISSION TYPE

0.0 SUMMARY

In Section 5.4 the expected number of Critical LRU replacements per mission type was given. Here the algorithm used to obtain the required data is discussed.

1.0 DEVELOPMENT OF A FUNCTION MISSION ORIENTED COMPONENT LEVEL PROBABILITY OF SUCCESS MODEL

It was pointed out in Section 5.4 that the mission debriefing data are functionally oriented. Thus, when a functional failure indication is observed, it is no longer obvious whether a particular LRU has failed or malfunctioned. Here the failures for a given LRU per mission are estimated by means of a probability of success model. The model describes the relationship between the failure of a given component and the associated aircraft functions. The functions considered are given on the F-111 Mission Debriefing Form 0-294 (see Figures 2.3.3 and 2.3.4).

In general, the functions associated with a given component are those functions affected by a failure of a particular component. The definitions of these functions are such that they are not independent. As a result, joint failures of functions occur. To describe this situation in probability terms, let

A denote the component in question,

S_i denote n independent functional subsets associated with A and

$P_F(S_i)$ denote the probability that S_i fails.

Due to the relationship between A and $\{S_i : i = 1, 2, \ldots, n\}$ it follows that

$$P_F(A) = \sum_{i=1}^{n} P_F(A \mid S_i)\, P_F(S_i). \qquad (1.1)$$

This expression coupled with $\{P_F(A|S_i),\ i = 1, 2, \ldots, n\}$ defines the model.

The S_i's can be found through detailed engineering analysis of the components relationship to the aircraft.

The $P_F(A|S_i)$'s are found by analyzing which components could cause a failure of a function contained in S_i. Let $C(S_i)$ be the set of components associated in this manner with S_i. The $C(S_i)$'s may be found by a slight modification of the process used to determine the functions associated with a given component. By definition

$$P_F(A|S_i) = n(A)/n(C(S_i)), \tag{1.2}$$

where $n(A)$ denotes the number of failure indications due to A and $n(C(S_i))$ denotes the number of failure indications due to elements of $C(S_i)$. Since A and $C(S_i)$ are defined in terms of Work Unit Codes $n(A)$ and $n(C(S_i))$ can be easily calculated from data retrieved from the 258 data base.

2.0 CALCULATION OF THE DISTRIBUTION OF OPERATING TIME OR CYCLES TO FAILURE FOR AIRCRAFT FUNCTIONS

The distribution of operating time to failure for the functions identified by the above method was calculated using F-111 Mission Debriefing Data. Strictly speaking, four different types of failure distributions were calculated by the following programs depending on the nature of the function. The four types of distributions calculated are the following:

(1) Operating hours to failure,

(2) Landings to failure,

(3) Wing sweeps to failure,

(4) Missions to failure.

The data were retrieved from the F-111 Mission Debriefing Data in SEDS data base by FFS and formatted for processing by a series of FORTRAN routines. These programs were used to calculate the distribution associated with a particular function. The routines which accomplished these tasks are described below.

(1) Select all records for a Critical LRU.

(2) For each Critical LRU output the following record.

AIRCRAFT NUMBER	COLS. 2-4
FUNCTION CODE	COLS. 5-8
RELATED ITEM CODE	COL. 9
1 - HOURS RELATED	
2 - LANDINGS RELATED	
3 - WING SWEEPS RELATED	
4 - MISSIONS RELATED	
FLIGHT DATE	COLS. 10-15
ACTUAL LANDING TIME	COLS. 16-19
NUMBER OF LANDINGS	COLS. 20-21
NUMBER OF WING SWEEPS	COLS. 22-23
ACTUAL TAKE-OFF TIME	COLS. 27-30
PHASES OF FLIGHT	COLS. 31-42

(3) Output the following as the final record:

(((	COLS. 2-4
((((	COLS. 5-8

3.0 PROCESSING THE DATA FROM FFS

The general processing procedure is outlined in Figure 3.1.

If files between steps are not indicated as tapes, they are on inter-system reserve units. The input to PHASCK (Figure 3.2) has the following format:

COL. 1	Blank
COLS. 2-4	AIRCRAFT NUMBER (A/C)
COLS. 5-8	4K-NUMBER
COL. 9	CODE relating 4K to hours, cycles, or missions

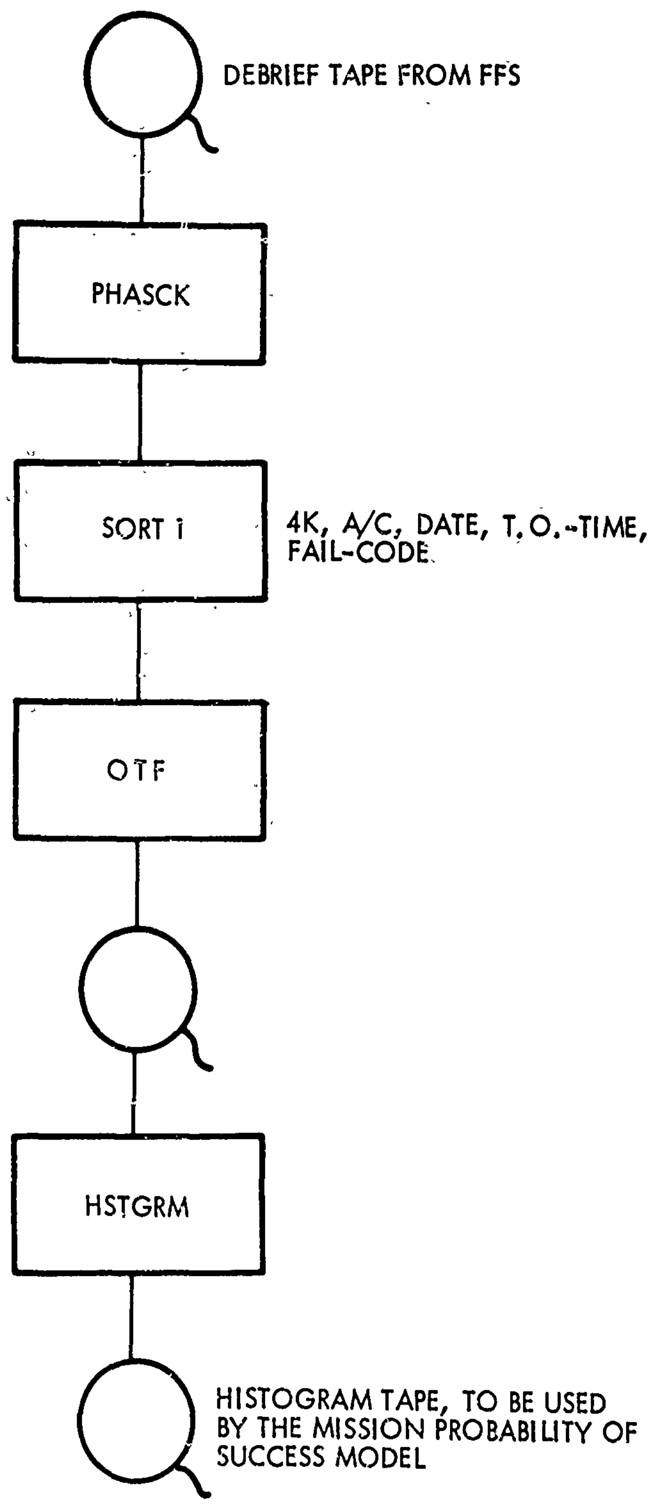

Figure 3.1: General Flow Chart of the Data Processing Requirements

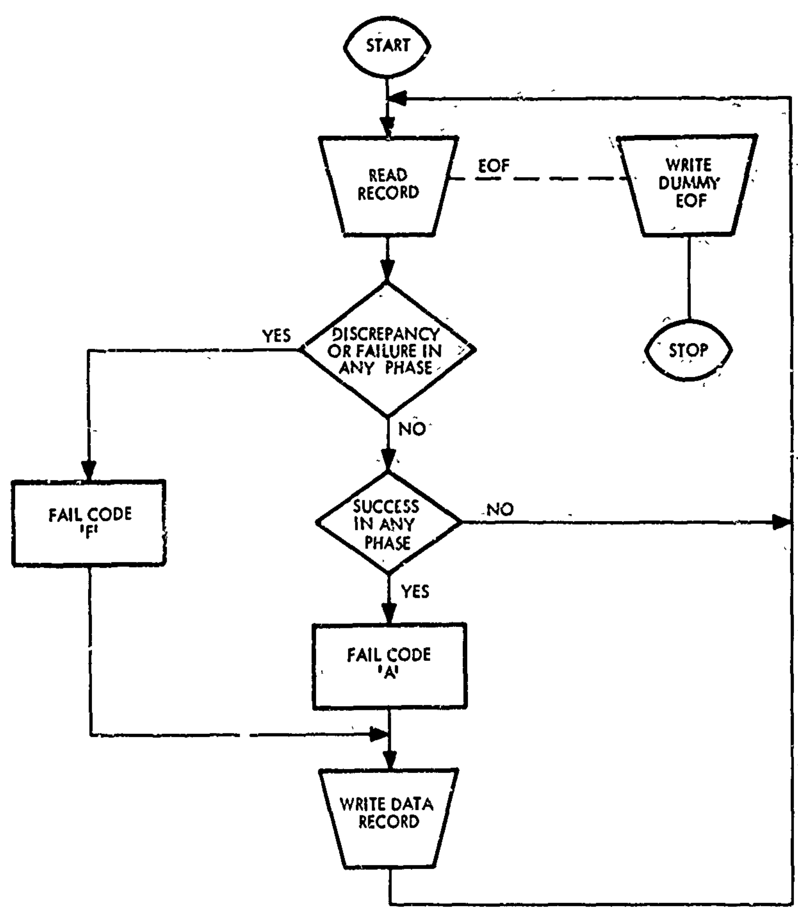

Figure 3.2: Flow Chart of PHASCK

COLS. 10-15	DATE
COLS. 16-19	MISSION LENGTH
COLS. 20-21	NUMBER LANDINGS
COLS. 22-23	NUMBER SWEEPS
COL. 24	FAIL-CODE
COL. 25	MISSION-CODE
COL. 26	BLANK
COLS. 27-30	TAKE-OFF-TIME
COLS. 31-42	12 1-CHARACTER PHASES

The last record on the tape is as follows:

COLS. 1-4	BLANK
COLS. 5-8	'(((('
COLS. 9-42	BLANK

Input to OTF (Figure 3.3) must be sorted on: 4K, A/C, DATE, TAKE-OFF-TIME, FAIL-CODE. The format is the following:

COL. 1	BLANK
COLS. 2-4	AIRCRAFT NUMBER (A/C)
COLS. 5-8	4K-NUMBER
COL. 9	CODE
COLS. 10-15	DATE
COLS. 16-19	MISSION LENGTH
COLS. 20-21	NUMBER LANDINGS
COLS. 22-23	NUMBER SWEEPS
COL. 24	FAIL-CODE
COL. 25	MISSION-CODE
COL. 26	BLANK
COLS. 27-30	TAKE-OFF TIME

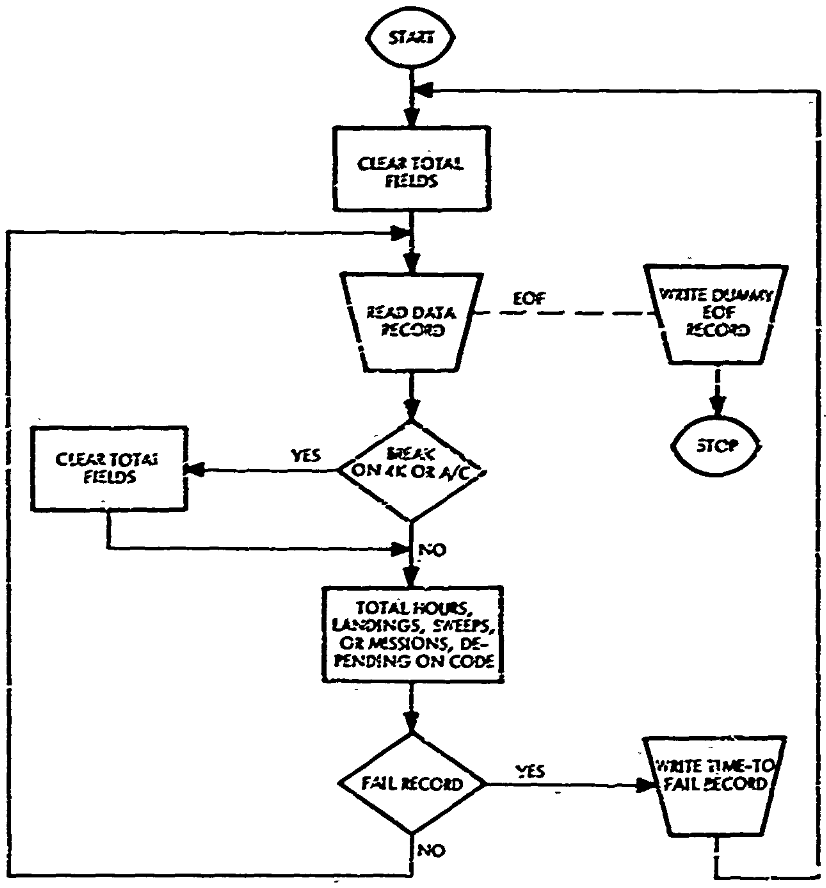

Figure 3.3: Flow Chart of OTF

The last record is as follows:

COL. 1	BLANK
COLS. 2-4	'((('
COLS. 5-30	BLANK

Input to HSTGRM (Figure 3.4) is the following:

COLS. 1-3	AIRCRAFT NUMBER (A/C)
COLS. 4-7	4K-NUMBER
COLS. 8-15	HOURS TO FAILURE
COLS. 16-17	LANDINGS TO FAILURE
COLS. 18-19	SWEEPS TO FAILURE
COLS. 20-21	MISSIONS TO FAILURE
COL. 22	CODE (pointer to one of the above 4 fields)
COLS. 23-24	BLANK

The last record is as follows:

COLS. 1-3	BLANK
COLS. 4-7	'(((('
COLS. 8-24	BLANK

The output from HSTGRM is sorted on 4K-NUMBER. Each 4K-NUMBER histogram is spread over 3 physical records.

(1)	COLS. 1-4	4K-NUMBER
	COLS. 5-94	First 10 points (F9.7)
	COLS. 95-100	BLANKS
(2)	COLS. 1-90	Second 10 points
	COLS. 91-100	BLANKS

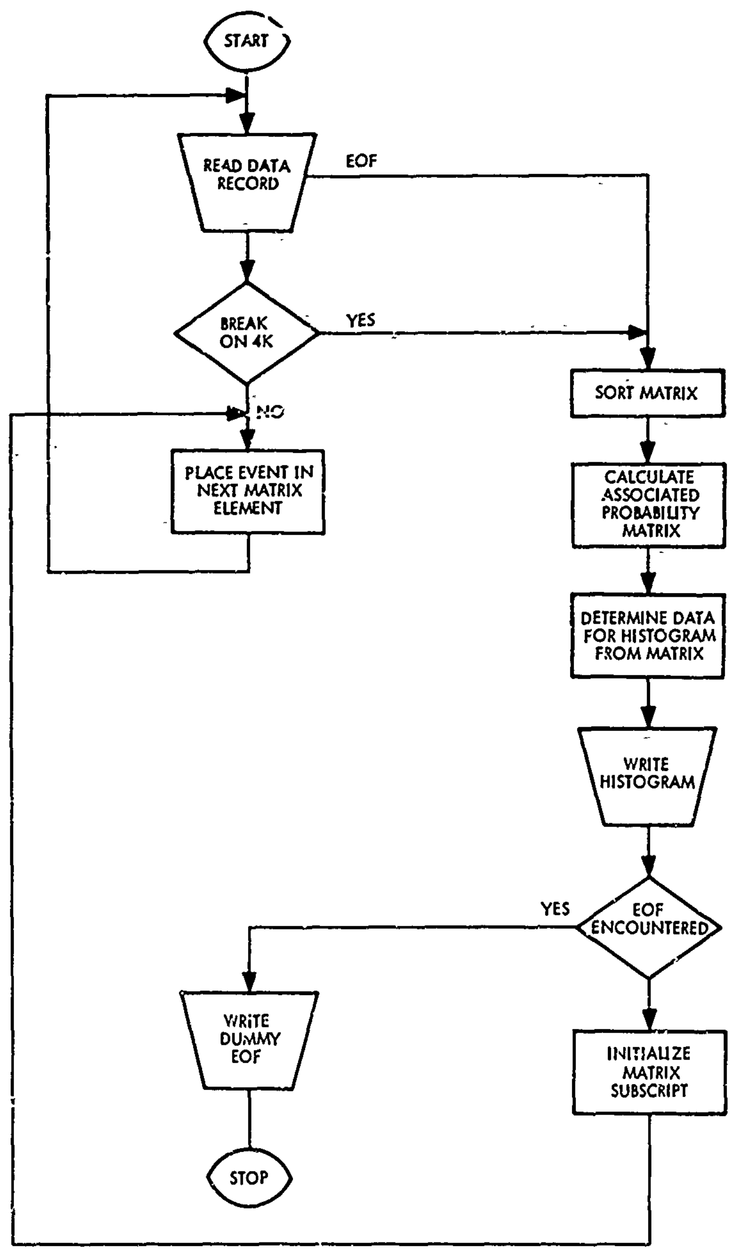

Figure 3.4: Flow Chart of HSTGRM

(3) COLS.	1-90	Last 10 points
COL.	91	CODE (hours, cycles, or missions)
COLS.	92-100	BLANK

A dummy EOF record is required.

COLS.	1-4	'9999'
COLS.	5-100	BLANKS

PHASCK examines every record from the DBRIEF input for failure or successful operation during any phase of the mission. For a failure or discrepancy in any phase, an 'F' FAIL-CODE is attached to the record. For successful operation, an 'A' FAIL-CODE is used.

SORT1 sorts the output of PHASCK on 4K-NUMBER, A/C-NUMBER, DATE, TAKE-OFF-TIME, FAIL-CODE.

OTF treats the data for each 4K-NUMBER within A/C-NUMBER separately. Each time to failure in terms of operating hours, wing sweeps, landings, or missions is calculated by totalling succeeding 'A' records and the first 'F' record encountered. Upon break on 4K-NUMBER or A/C-NUMBER, total fields are cleared and calculations start again.

DESCRIPTION OF KEY VARIABLES

ISER	A/C-NUMBER
IFOURK	4K-NUMBER
ICODE	Code relating 4K-NUMBER to hours, landings, sweeps or missions
IHRS	
IMIN	Mission duration
NUMLDG	Number of landings
NUMSWP	Number of Wing Sweeps
IFAIL	Success or Fail (A or F) Code

MISCOD	Mission Code (first record from DBRIEF or 258)
TOTHRS	Hours to Failure
ILDGS	Landings to Failure
ISWPS	Sweeps to Failure
IMISS	Missions to Failure.

HSTGRM reads all the data for a particular 4K-NUMBER into a matrix. The matrix is sorted internally. The inverse of the number of items in the matrix (the probability of each event occurring is calculated. A value of 1 times the probability is associated with the first matrix element, a value of 2 times the probability is associated with the second matrix element, etc. For each of the 30 points on the histogram (0.5 hours between points for hours-related 4K-NUMBERS; integer points for landings, sweeps, and mission-related 4K-NUMBERS) either the 2 matrix elements surrounding the point desired are found, or the matrix element corresponding exactly to the point desired is found. The desired probability of failure is either interpolated from the 2 surrounding probabilities, or corresponding point is used. The actual histogram is spread over three physical records (see record formats above).

Because problems were encountered in determining end of the input file, two MAP routines are used. BTPIO incorporates various tape handling facilities. The file open (FOPEN) routine is used by HSTGRM. SKIP does a binary tape read and returns a count of words read. A count of 0 indicates EOF. HSTGRM calls SKIP and then if the count returned is non-zero, it backspaces the tape and does a FORTRAN read.

DESCRIPTION OF KEY VARIABLES

AMATRX	Hours to Failure Matrix
IMATRX	Cycles to Failure Matrix
BMATRX	Histogram Matrix

PMATRX	Probability Matrix Associated with AMATRX
PROBA	Probability of each event (inverse of the number of events).

Also see OTF variables above.

APPENDIX V

THE EVALUATION OF CURRENT REPLACEMENT REQUIREMENTS

In Section 5.5 the 50, 85, 90 and 95 percentile points of the probability distribution of K for each LRU were given. Here the plots and the results of goodness of fit tests on the sample distribution of K are given. It is recognized, however, that K is approximately normally distributed by the Central Limit Theorem from Probability and statistics since

$$K = \sum_{j=1}^{10} p_j K_j$$

in an average. Thus, it is not surprising that the Kolmogorov-Smirnov test supports this fact (see Table 1). However, these results conclude the investigation.

Table 1: Decision to reject the null hypothesis that the sample distribution of K-value for a random mixture of missions approximates a given theoretical distribution function, where $\alpha = 0.05$.

Critical LRU	$H_{0,j}: S_n(t) \equiv F(t\|\theta)$	Sample Size	Graph	D_n	$1 - Q(D_n\sqrt{n})$	Decision
1. Amplifier, lead and launch computing WUC 74AAB	N(0.38, 0.003)	500	1	0.0553	0.0943	
2. Turbine, Cooling WUC 41ABA	N(0.13, 0.00003)	500	2	0.0297	0.7680	
3. Transmitter/Receiver WUC 73CAO	N(2.63, 0.003)	500	3	0.0269	0.8598	
4. Synchronizer, Transmitter WUC 73DFO	N(0.73, 0.01)	500	4	0.0444	0.2785	
5. Modulator, Receiver/Transmitter WUC 73BDC	N(1.22, 0.006)	500	5	0.0390	0.4302	
6. Computer, Air Data WUC 52BAA	N(1.96, 0.001)	500	6	0.0256	0.8977	
7. Mach Assembly, Maximum Safe WUC 52BBR	-	-		-	-	
8. Computer, Flight Control, Yaw WUC 52ACA	N(0.37, 0.0002)	500	7	0.0166	0.9991	
9. Stabilization Platform Unit WUC 73AAO	N(5.39, 0.14)	500	8	0.0237	0.9406	
10. Feel Trim Assembly WUC 52ADA	-	-		-	-	
11. Navigational Computer CP812/AJQ-20 WUC 73ABO	N(7.77, 0.12)	500	9	0.0263	0.8792	

Source: 258 Data System and the Mission Debriefing Form 0-294 for the F-111, Edwards AFB, California.
K-value = Expected number of replacements per 100 operating hours.
$N(\mu, \sigma^2)$ = A normal distribution with mean μ and variance σ^2

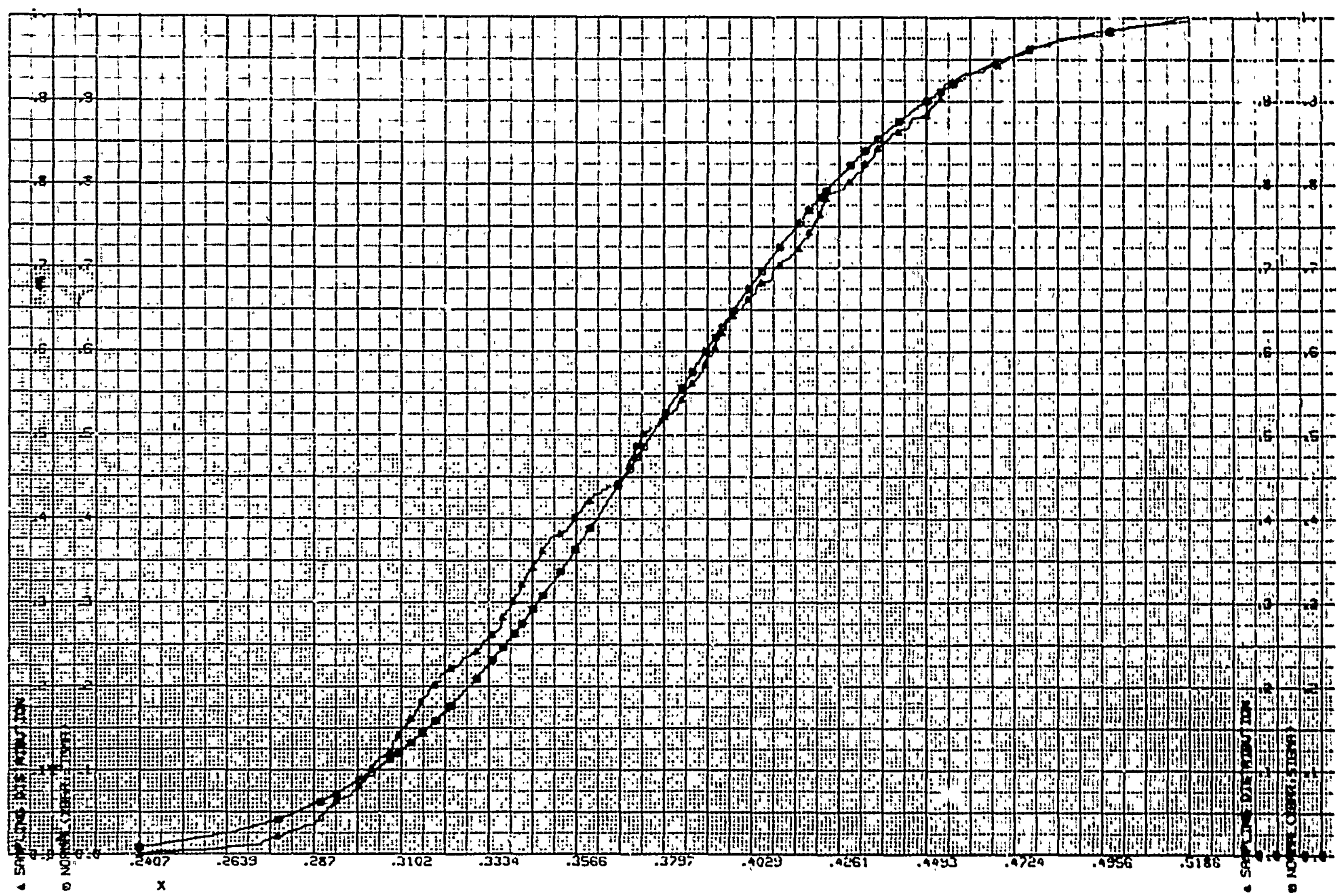

Figure 1. Test for Normality: K-Value Distribution for Random Mission Mixture Critical LRU - Amplifier, Lead and Launch Computing (WUC 74AAB)

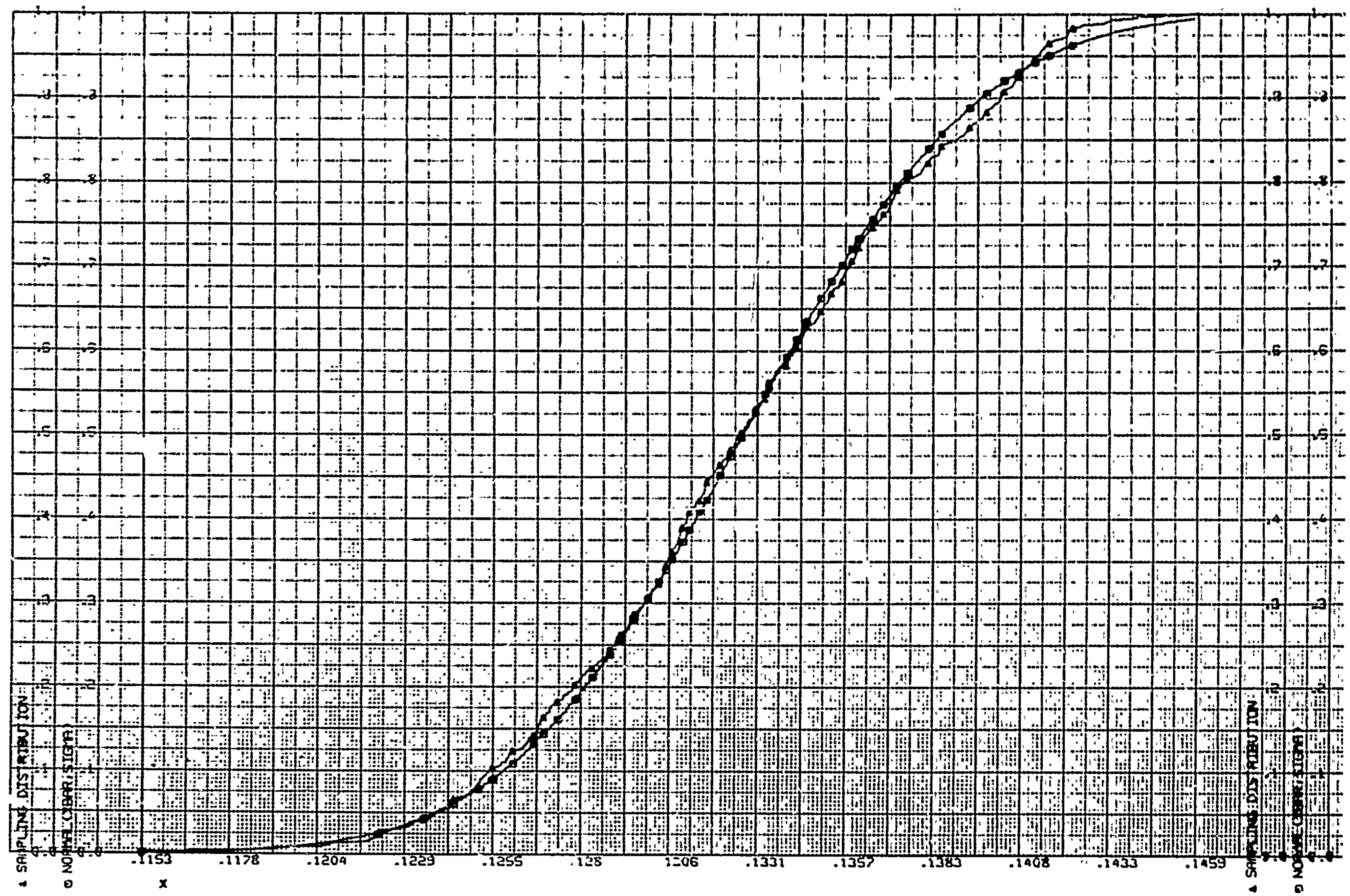

Figure 2. Test for Normality: K-Value Distribution for Random Mission Mixture Critical LRU - Turbine, Cooling (WUC 41ABA)

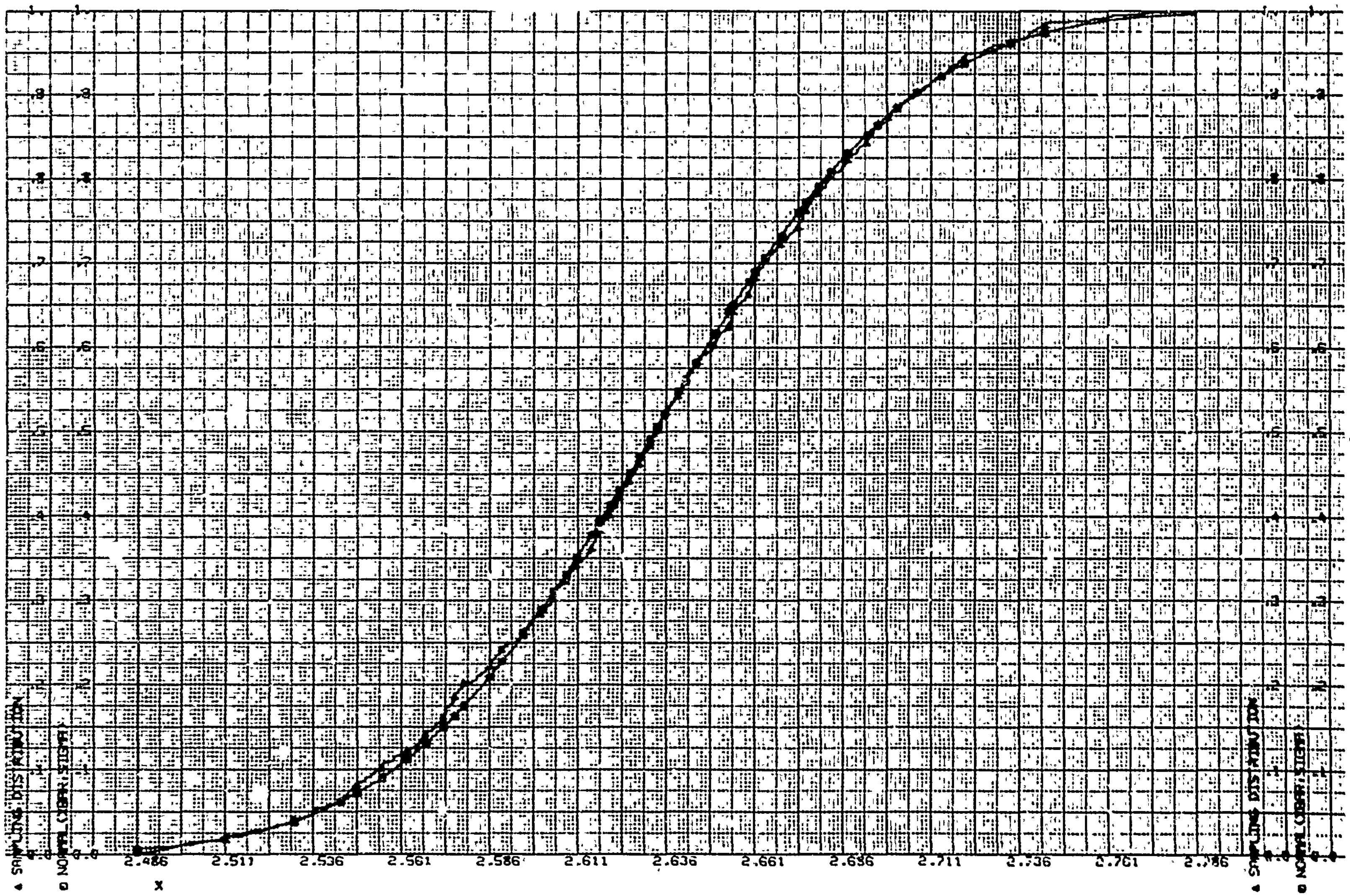

Figure 3. Test for Normality: K-Value Distribution for Random Mission Mixture Critical LRU - Transmitter/Receiver (WUC 73CAO)

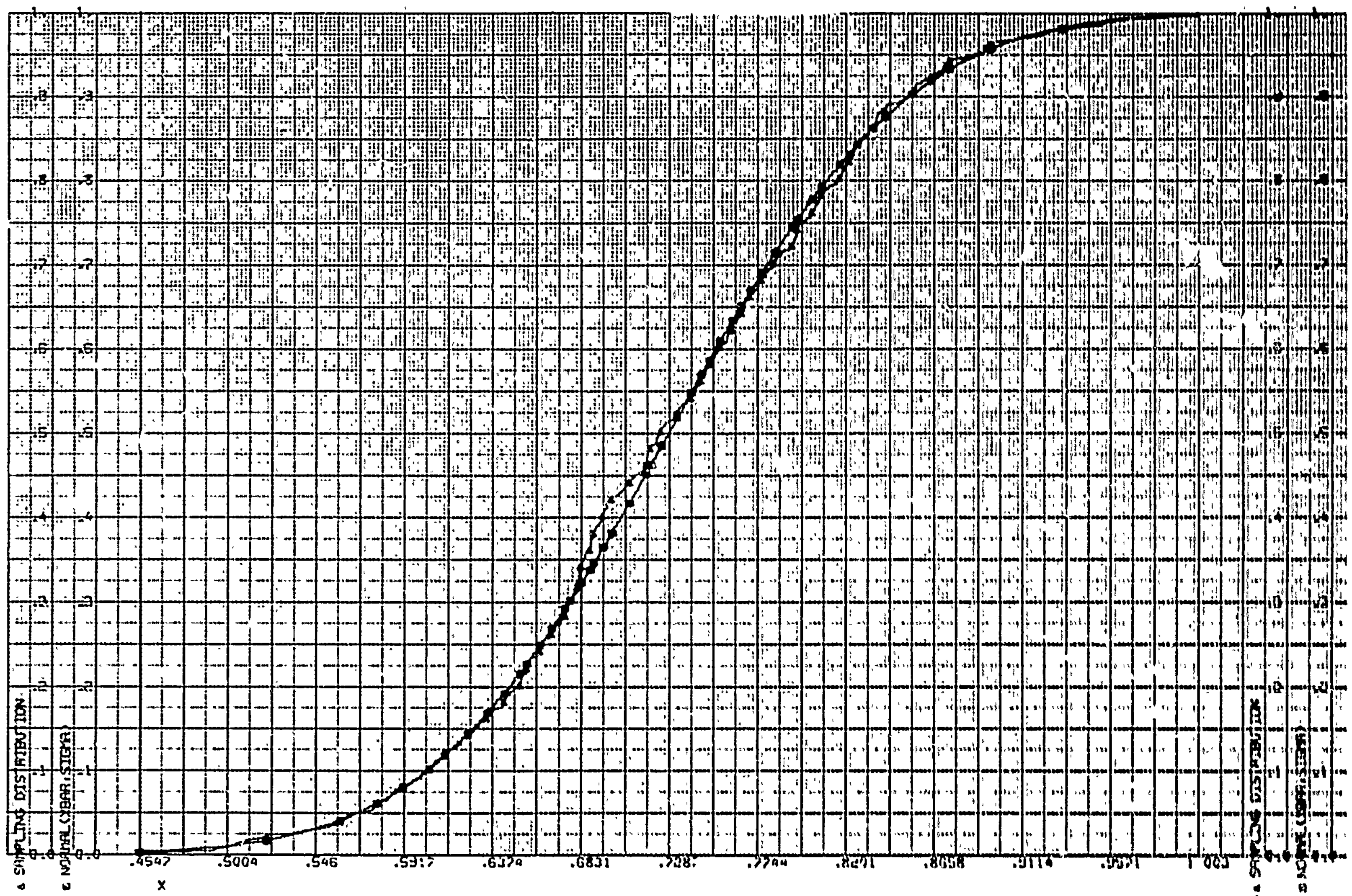

Figure 4. Test for Normality: K-Value Distribution for Random Mission Mixture Critical LRU - Synchronizer, Transmitter (WUC 73DFO)

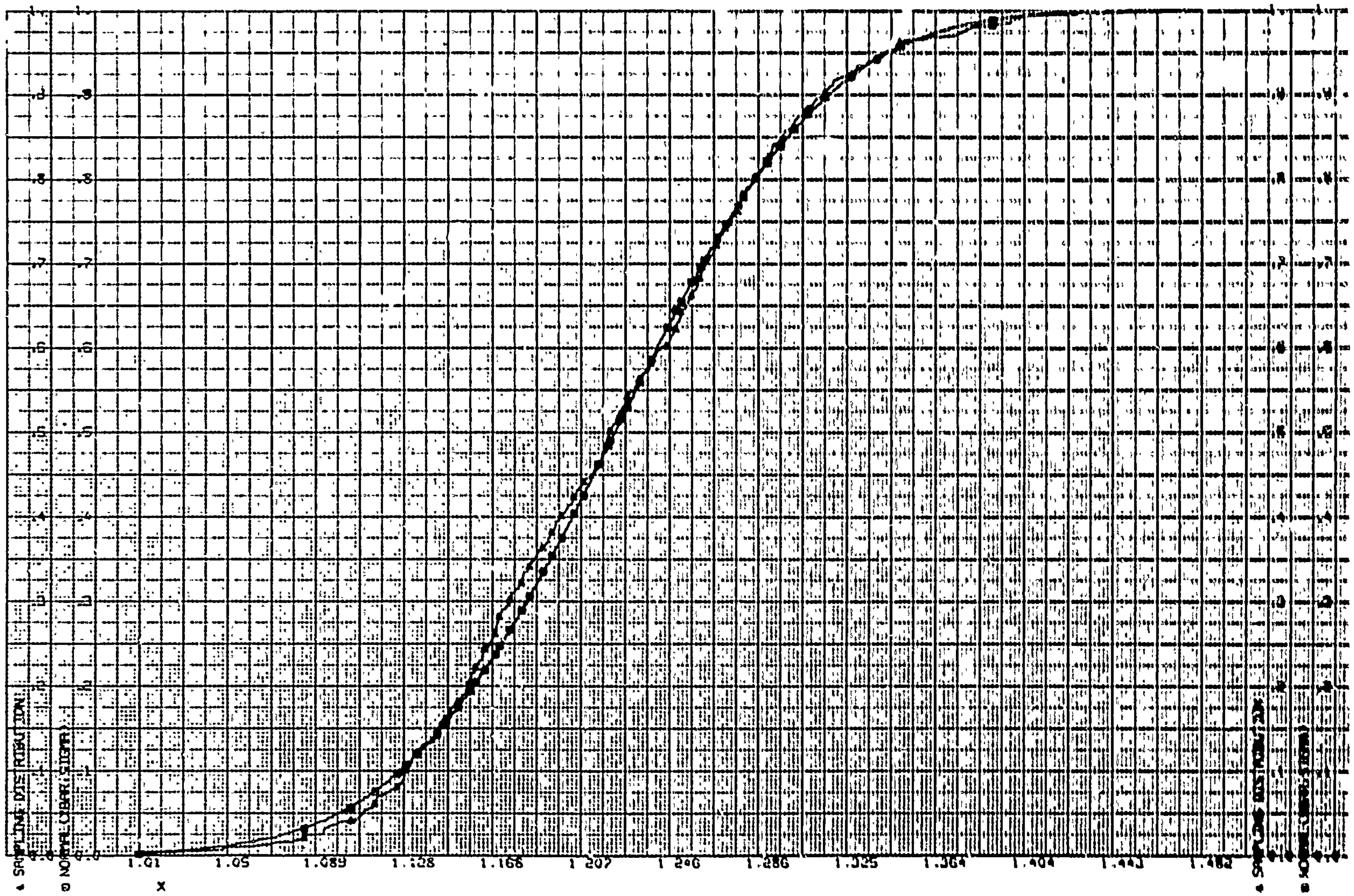

Figure 5. Test for Normality: K-Value Distribution for Random Mission Mixture Critical LRU - Modulator, Receiver/Transmitter (WUC 73BDO)

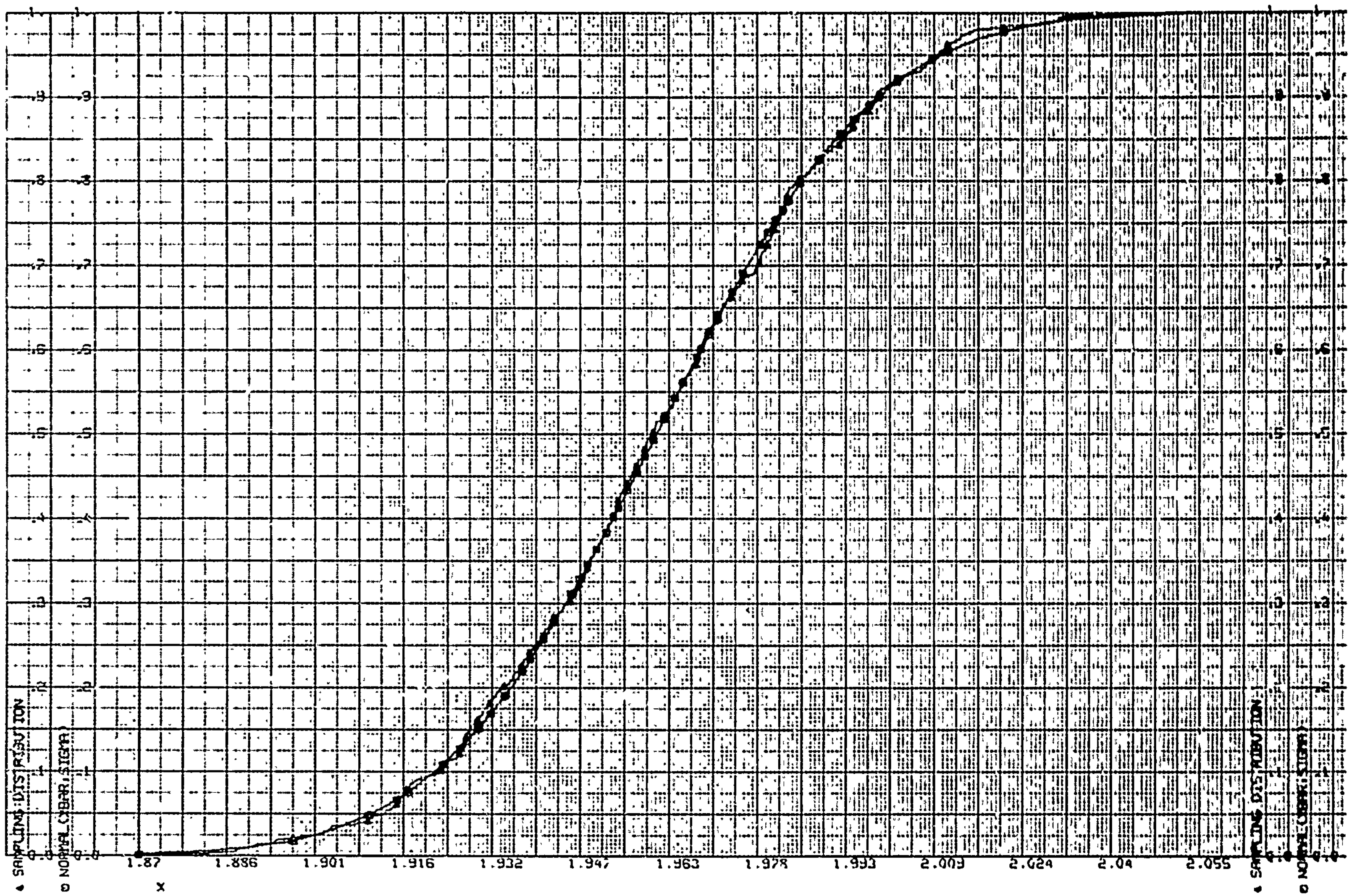

Figure 6. Test for Normality: K-Value Distribution for Random Mission Mixture Critical LRU - Computer, Air Data (WUC 52BAA)

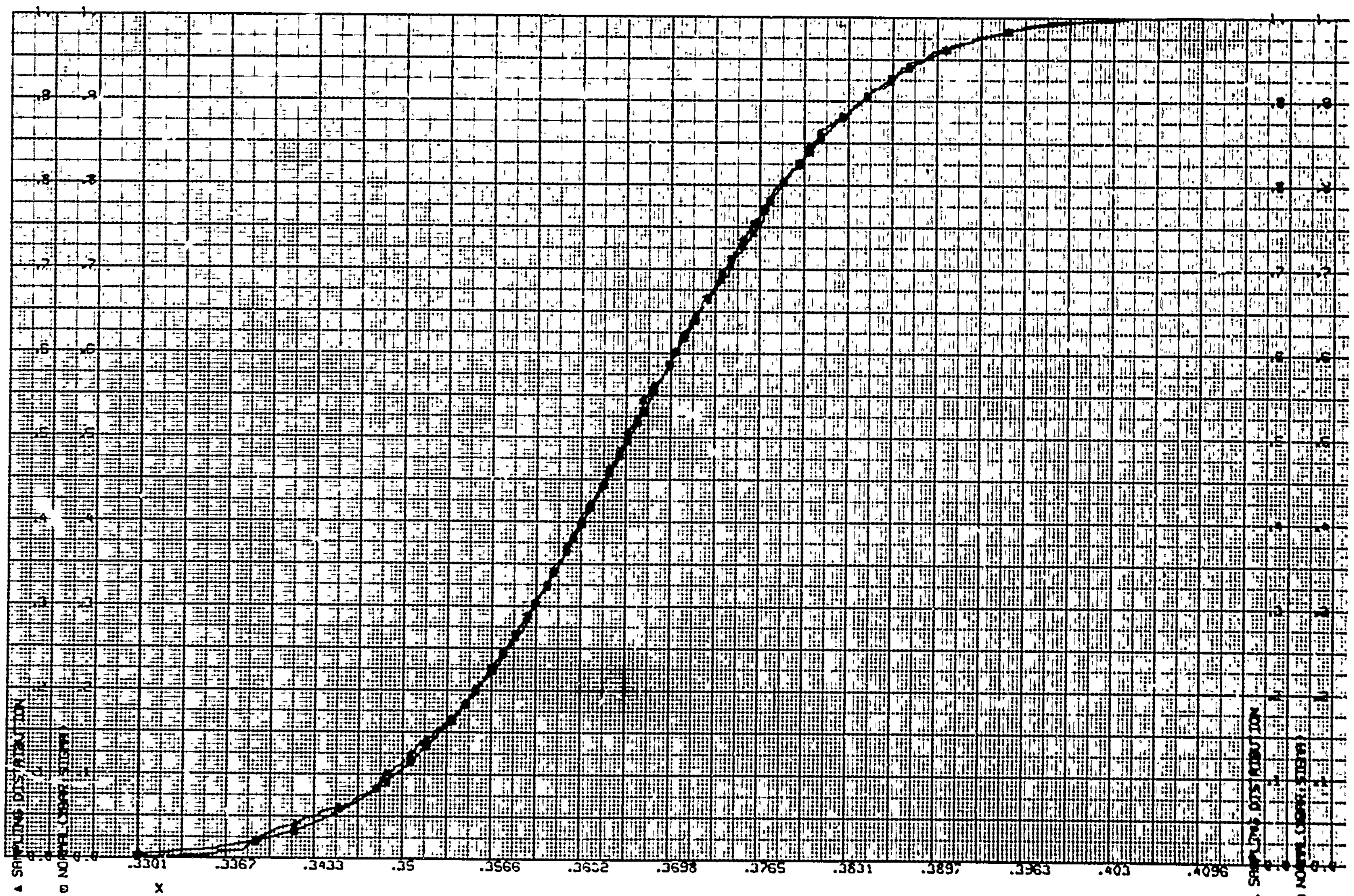

Figure 7. Test for Normality: K-Value Distribution for Random Mission Mixture Critical LRU - Computer, Flight Control (WUC 52ACA)

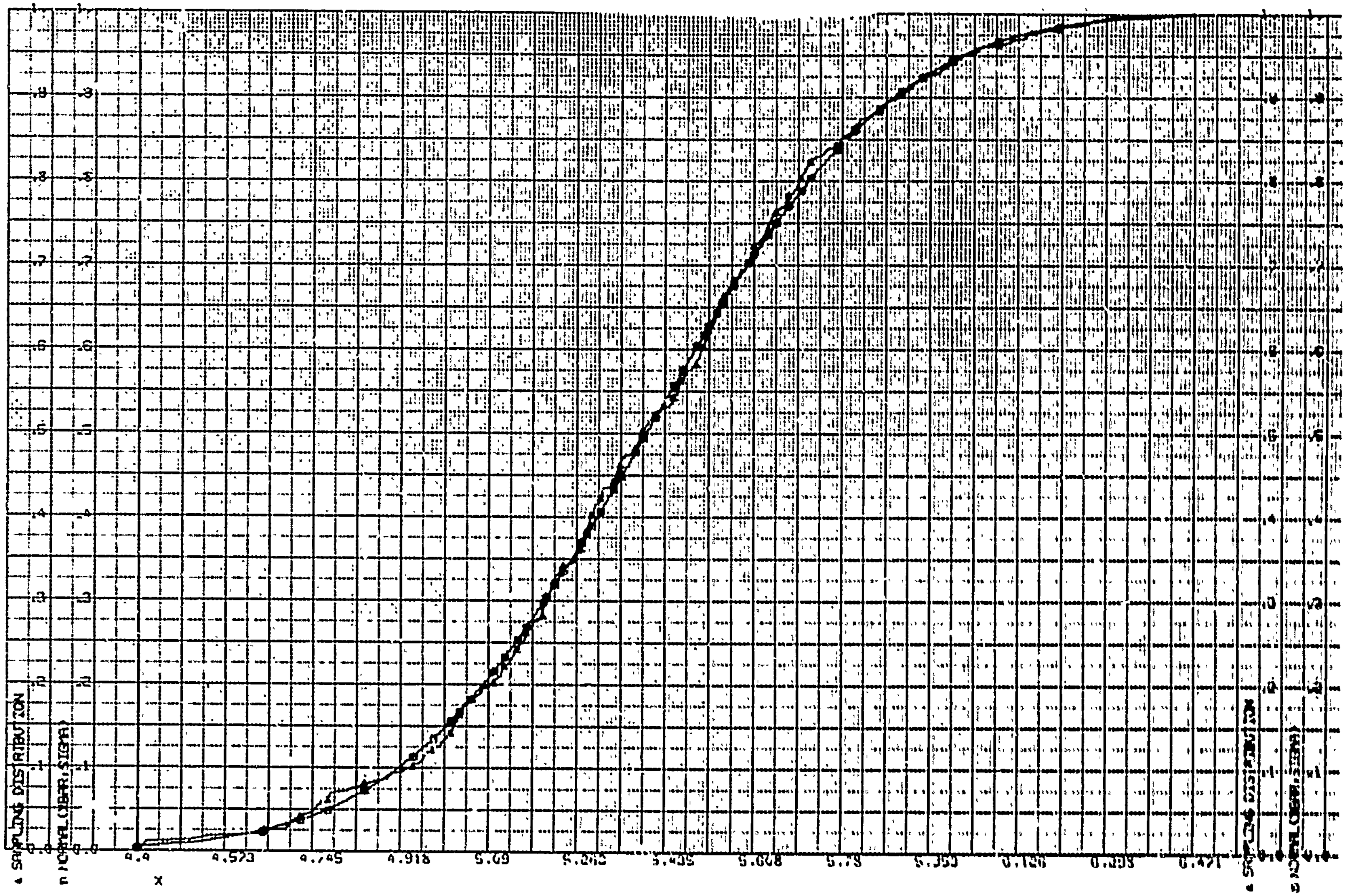

Figure 8. Test for Normality: K-Value Distribution for Random Mission Mixture Critical LRU - Stabilization Platform Unit (WUC 73AAO)

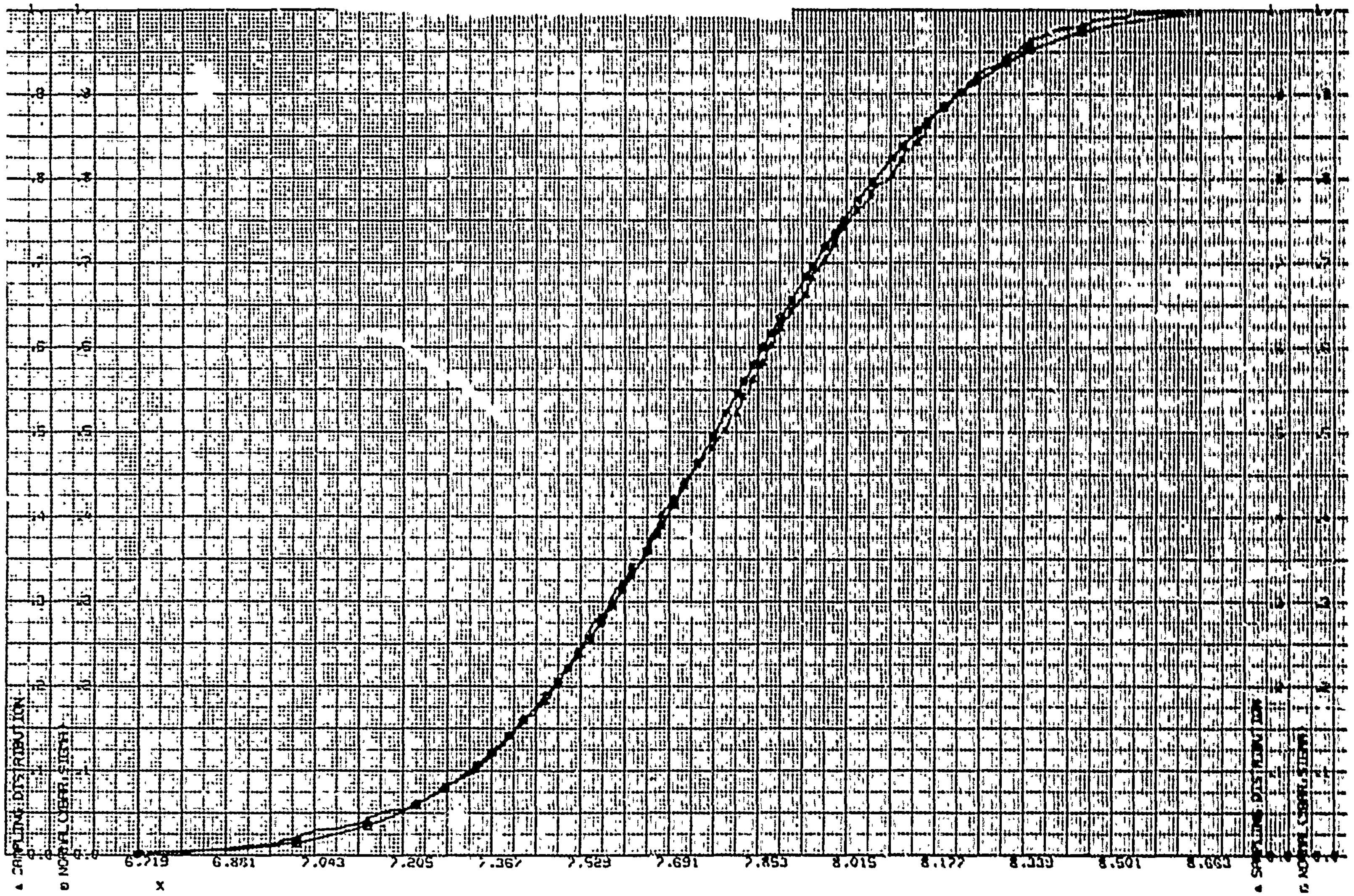

Figure 9. Test for Normality: K-Value Distribution for Random Mission Mixture Critical LRU - Navigation Computer CP812/AJQ-2 WUC 73ABO

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13. ABSTRACT

This report represents the System Effectiveness Data System (SEDS) effort and was conducted at Edwards AFB on the IBM 7044/7094 computer. F-111A Catagory II operating and maintenance data was stored on tapes using the IBM Formatted File System (FFS-V8). Problems were defined by the F-111 System Project Office (SPO) and the Sacramento Air Materiel Area. These problems were associated with the eleven most critical line replaceable units (LRUs) in the F-111. The problems were: -(1) Distribution of total maintenance for each LRU; (2) Relationships between LRU replacement and failures; (3) Replacement estimate for each mission type; (4) Estimate for replacements per 100 flying hours for each LRU. Solutions were provided for problems: (1) for both flight line and shop activities where the event was defined as all activity associated with the total system. Problems (2) and (3) were solved as planned. Problem (4) was solved as planned with the additional result of the probability distribution associated with each LRU replacement requirement. Hence, the risk associated with a given replacement value is quantitatively indicated. This study demonstrated that storage and retrieval of a large volume of operating and maintenance data on a timely basis appears feasible. Also, that Catagory II operating data can be used to provide relatively accurate estimates of system operating parameters and/or requirements. This study further demonstrates the usefulness of 258/mission debriefing data for providing estimates of reliability/maintainability parameters and other information.

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